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Search Results -

Term	Documents
CONTROL$6	0
CONTROL.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	4407720
CONTROLA.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	27
CONTROLAB.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABALE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABILIY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABILTY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	2
CONTROLABITY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABL.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABLE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	704
CONTROLABLES.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
. . . . .	
CONTROL$6(CONTROL-YOKE).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	pickup term
(L14 AND ((CONTROL$6 OR STEER$5 OR DIRECT$5) WITH CURRENT)).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	6

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Search: L15

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Search History

DATE: Wednesday, June 05, 2002 Printable Copy Create Case

Set Name side by side	**Query**	**Hit Count**	**Set Name** result set
	DB=USPT,PGPB,JPAB,EPAB,DWPI,TDBD; PLUR=YES; OP=ADJ		
L15	L14 and ((control$6 or steer$5 or direct$5) with current)	6	L15
L14	L13 and (load)	6	L14
L13	L12 and (circuit$4)	8	L13
L12	L11 and (value)	9	L12
L11	L10 and (conduct$7 or state or path)	9	L11
L10	L9 and (magnitude with current)	9	L10
L9	L8 and (magnitude)	58	L9
L8	L7 and (gradient or (gradient with coil) or assembly)	88	L8
L7	L6 and ((duration or length or width) with pulse)	114	L7
L6	L5 and (current)	329	L6
L5	L4 and (amplif$7)	401	L5
L4	L3 and (parallel)	718	L4
L3	L2 and (threshold$4)	1313	L3
L2	L1 and (switch$5)	8732	L2
L1	((magnetic adj resonance) or MRI or NMR)	129662	L1

END OF SEARCH HISTORY

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Search Results - Record(s) 1 through 9 of 9 returned.

☐ 1. Document ID: US 20010018547 A1

L12: Entry 1 of 9 File: PGPB Aug 30, 2001

PGPUB-DOCUMENT-NUMBER: 20010018547
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20010018547 A1

TITLE: Muscle stimulating device and method for diagnosing and treating a breathing disorder

PUBLICATION-DATE: August 30, 2001

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY	RULE-47
Mechlenburg, Douglas M.	Pittsburgh	PA	US	
Gaumond, Roger Paul	State College	PA	US	

US-CL-CURRENT: 600/15; 600/529

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 2. Document ID: US 6353354 B1

L12: Entry 2 of 9 File: USPT Mar 5, 2002

US-PAT-NO: 6353354
DOCUMENT-IDENTIFIER: US 6353354 B1

TITLE: Pulse-width modulated bridge circuit within a second bridge circuit

DATE-ISSUED: March 5, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Detweiler; James P.	Lansdale	PA		
Goff; Jerry K.	late of Doyleston	PA		

US-CL-CURRENT: 327/423; 327/110

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw Desc | Image

☐ 3. Document ID: US 6163201 A

L12: Entry 3 of 9 File: USPT Dec 19, 2000

US-PAT-NO: 6163201
DOCUMENT-IDENTIFIER: US 6163201 A

TITLE: Circuit for supplying a load with a direct voltage

DATE-ISSUED: December 19, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Schweighofer; Peter	Nuremberg			DEX

US-CL-CURRENT: 327/496; 327/531, 327/587

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC | Draw Desc | Image

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4. Document ID: US 6140873 A

L12: Entry 4 of 9 File: USPT Oct 31, 2000

US-PAT-NO: 6140873
DOCUMENT-IDENTIFIER: US 6140873 A

TITLE: Power amplifier with soft switching and multilevel switching cells

DATE-ISSUED: October 31, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Van Groningen; Wilhelmus D.H.	Eindhoven			NLX

US-CL-CURRENT: 330/10; 330/207A, 330/251, 363/132

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC | Draw Desc | Image

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5. Document ID: US 6111458 A

L12: Entry 5 of 9 File: USPT Aug 29, 2000

US-PAT-NO: 6111458
DOCUMENT-IDENTIFIER: US 6111458 A

TITLE: Power amplifier and nuclear spin tomography apparatus employing same

DATE-ISSUED: August 29, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ideler; Karl-Heinz	Spardorf			DEX

US-CL-CURRENT: 327/588; 327/108, 327/423

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 6. Document ID: US 6031422 A

L12: Entry 6 of 9 File: USPT Feb 29, 2000

US-PAT-NO: 6031422
DOCUMENT-IDENTIFIER: US 6031422 A

TITLE: Power amplifier and nuclear magnetic resonance tomography apparatus employing same

DATE-ISSUED: February 29, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ideler; Karl-Heinz	Spardorf			DEX

US-CL-CURRENT: 330/10; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 7. Document ID: US 5955909 A

L12: Entry 7 of 9 File: USPT Sep 21, 1999

US-PAT-NO: 5955909
DOCUMENT-IDENTIFIER: US 5955909 A

TITLE: Device for monitoring chip temperature

DATE-ISSUED: September 21, 1999

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Lenz; Helmut	Oberasbach			DEX
Burger; Walter	Nurenberg			DEX

US-CL-CURRENT: 327/361; 307/651, 327/512

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 8. Document ID: US 5502576 A

L12: Entry 8 of 9 File: USPT Mar 26, 1996

US-PAT-NO: 5502576
DOCUMENT-IDENTIFIER: US 5502576 A

TITLE: Method and apparatus for the transmission, storage, and retrieval of documents in an electronic domain

DATE-ISSUED: March 26, 1996

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ramsay; Thomas E.	Minneapolis	MN		
Elkins; James C.	Golden Valley	MN		

US-CL-CURRENT: 358/444; 358/403, 358/404

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw. Desc | Image

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9. Document ID: US 4910460 A

L12: Entry 9 of 9 File: USPT Mar 20, 1990

US-PAT-NO: 4910460
DOCUMENT-IDENTIFIER: US 4910460 A

TITLE: Method and apparatus for mapping eddy currents in magnetic resonance imaging

DATE-ISSUED: March 20, 1990

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Sebok; David A.	Plainsboro	NJ		

US-CL-CURRENT: 324/307; 324/300

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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Term	Documents
VALUE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	2165818
VALUES.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	989347
(11 AND VALUE).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	9
(L11 AND (VALUE)).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	9

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Search Results - Record(s) 1 through 8 of 8 returned.

☐ 1. Document ID: US 20010018547 A1

L13: Entry 1 of 8 File: PGPB Aug 30, 2001

PGPUB-DOCUMENT-NUMBER: 20010018547
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20010018547 A1

TITLE: Muscle stimulating device and method for diagnosing and treating a breathing disorder

PUBLICATION-DATE: August 30, 2001

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY	RULE-47
Mechlenburg, Douglas M.	Pittsburgh	PA	US	
Gaumond, Roger Paul	State College	PA	US	

US-CL-CURRENT: 600/15; 600/529

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 2. Document ID: US 6353354 B1

L13: Entry 2 of 8 File: USPT Mar 5, 2002

US-PAT-NO: 6353354
DOCUMENT-IDENTIFIER: US 6353354 B1

TITLE: Pulse-width modulated bridge circuit within a second bridge circuit

DATE-ISSUED: March 5, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Detweiler; James P.	Lansdale	PA		
Goff; Jerry K.	late of Doyleston	PA		

US-CL-CURRENT: 327/423; 327/110

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 3. Document ID: US 6163201 A

L13: Entry 3 of 8 File: USPT Dec 19, 2000

US-PAT-NO: 6163201
DOCUMENT-IDENTIFIER: US 6163201 A

TITLE: Circuit for supplying a load with a direct voltage

DATE-ISSUED: December 19, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Schweighofer; Peter	Nuremberg			DEX

US-CL-CURRENT: 327/496; 327/531, 327/587

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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4. Document ID: US 6140873 A

L13: Entry 4 of 8 File: USPT Oct 31, 2000

US-PAT-NO: 6140873
DOCUMENT-IDENTIFIER: US 6140873 A

TITLE: Power amplifier with soft switching and multilevel switching cells

DATE-ISSUED: October 31, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Van Groningen; Wilhelmus D.H.	Eindhoven			NLX

US-CL-CURRENT: 330/10; 330/207A, 330/251, 363/132

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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5. Document ID: US 6111458 A

L13: Entry 5 of 8 File: USPT Aug 29, 2000

US-PAT-NO: 6111458
DOCUMENT-IDENTIFIER: US 6111458 A

TITLE: Power amplifier and nuclear spin tomography apparatus employing same

DATE-ISSUED: August 29, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ideler; Karl-Heinz	Spardorf			DEX

US-CL-CURRENT: 327/588; 327/108, 327/423

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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6. Document ID: US 6031422 A

L13: Entry 6 of 8 File: USPT Feb 29, 2000

US-PAT-NO: 6031422
DOCUMENT-IDENTIFIER: US 6031422 A

TITLE: Power amplifier and nuclear magnetic resonance tomography apparatus employing same

DATE-ISSUED: February 29, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ideler; Karl-Heinz	Spardorf			DEX

US-CL-CURRENT: 330/10; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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7. Document ID: US 5955909 A

L13: Entry 7 of 8 File: USPT Sep 21, 1999

US-PAT-NO: 5955909
DOCUMENT-IDENTIFIER: US 5955909 A

TITLE: Device for monitoring chip temperature

DATE-ISSUED: September 21, 1999

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Lenz; Helmut	Oberasbach			DEX
Burger; Walter	Nurenberg			DEX

US-CL-CURRENT: 327/361; 307/651, 327/512

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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8. Document ID: US 5502576 A

L13: Entry 8 of 8 File: USPT Mar 26, 1996

US-PAT-NO: 5502576
DOCUMENT-IDENTIFIER: US 5502576 A

TITLE: Method and apparatus for the transmission, storage, and retrieval of documents in an electronic domain

DATE-ISSUED: March 26, 1996

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ramsay; Thomas E.	Minneapolis	MN		
Elkins; James C.	Golden Valley	MN		

US-CL-CURRENT: 358/444; 358/403, 358/404

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC

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Term	Documents
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CIRCUIT.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	2977052
CIRCUITA.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	29
CIRCUITABLE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	69
CIRCUITABLY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CIRCUITAIR.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CIRCUITAL.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	390
CIRCUITALLY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	70
CIRCUITAN.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CIRCUITAND.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	40
CIRCUITAPE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
(L12 AND (CIRCUIT$4)).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	8

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Search Results - Record(s) 1 through 6 of 6 returned.

☐ 1. Document ID: US 6353354 B1

L15: Entry 1 of 6 File: USPT Mar 5, 2002

US-PAT-NO: 6353354
DOCUMENT-IDENTIFIER: US 6353354 B1

TITLE: Pulse-width modulated bridge circuit within a second bridge circuit

DATE-ISSUED: March 5, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Detweiler; James P.	Lansdale	PA		
Goff; Jerry K.	late of Doyleston	PA		

US-CL-CURRENT: 327/423; 327/110

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw Desc | Image

☐ 2. Document ID: US 6163201 A

L15: Entry 2 of 6 File: USPT Dec 19, 2000

US-PAT-NO: 6163201
DOCUMENT-IDENTIFIER: US 6163201 A

TITLE: Circuit for supplying a load with a direct voltage

DATE-ISSUED: December 19, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Schweighofer; Peter	Nuremberg			DEX

US-CL-CURRENT: 327/496; 327/531, 327/587

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw Desc | Image

☐ 3. Document ID: US 6140873 A

L15: Entry 3 of 6 File: USPT Oct 31, 2000

US-PAT-NO: 6140873
DOCUMENT-IDENTIFIER: US 6140873 A

TITLE: Power amplifier with soft switching and multilevel switching cells

DATE-ISSUED: October 31, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Van Groningen; Wilhelmus D.H.	Eindhoven			NLX

US-CL-CURRENT: 330/10; 330/207A, 330/251, 363/132

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments KWIC
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☐ 4. Document ID: US 6111458 A

L15: Entry 4 of 6 File: USPT Aug 29, 2000

US-PAT-NO: 6111458
DOCUMENT-IDENTIFIER: US 6111458 A

TITLE: Power amplifier and nuclear spin tomography apparatus employing same

DATE-ISSUED: August 29, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ideler; Karl-Heinz	Spardorf			DEX

US-CL-CURRENT: 327/588; 327/108, 327/423

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments KWIC
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☐ 5. Document ID: US 6031422 A

L15: Entry 5 of 6 File: USPT Feb 29, 2000

US-PAT-NO: 6031422
DOCUMENT-IDENTIFIER: US 6031422 A

TITLE: Power amplifier and nuclear magnetic resonance tomography apparatus employing same

DATE-ISSUED: February 29, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Ideler; Karl-Heinz	Spardorf			DEX

US-CL-CURRENT: 330/10; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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☐ 6. Document ID: US 5955909 A

L15: Entry 6 of 6 File: USPT Sep 21, 1999

US-PAT-NO: 5955909
DOCUMENT-IDENTIFIER: US 5955909 A

TITLE: Device for monitoring chip temperature

DATE-ISSUED: September 21, 1999

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
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Burger; Walter	Nurenberg			DEX

US-CL-CURRENT: 327/361; 307/651, 327/512

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
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Term	Documents
CONTROL$6	0
CONTROL.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	4407720
CONTROLA.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	27
CONTROLAB.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABALE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABILIY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABILTY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	2
CONTROLABITY.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABL.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
CONTROLABLE.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	704
CONTROLABLES.DWPI,TDBD,EPAB,JPAB,USPT,PGPB.	1
(L14 AND ((CONTROL$6 OR STEER$5 OR DIRECT$5) WITH CURRENT)).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	6

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L15: Entry 2 of 6 File: USPT Dec 19, 2000

DOCUMENT-IDENTIFIER: US 6163201 A
TITLE: Circuit for supplying a load with a direct voltage

Abstract Paragraph Left (1):
In a circuit for supplying a load with a direct voltage, a diode is connected in a current path for supplying the load, a step-up converter is connected in the current paths parallel with the diode, and a control unit drives the step-up converter according to predetermined criteria in order to supply the load at least partially via the step-up converter. Such a circuit has advantageous power consumption characteristics. In comparison to conventional circuits that require an expensive filter, this circuit is more economical and/or has a smaller structural size.

Brief Summary Paragraph Right (2):
The invention relates to a circuit for supplying a load with a direct voltage, in particular, for use in high-voltage power supply units, e.g. in the kW range. Such a power supply unit can, for example, be the power supply unit of a gradient amplifier or a resonance converter for a magnetic resonance tomograph apparatus, however, such a circuit is suitable for all other types of high-performance power supply units.

Brief Summary Paragraph Right (4):
In order to supply a load with a direct voltage, the principle of rectification with capacitive smoothing is often applied. FIG. 1 shows, for example, a one-way rectifier in which a network alternating voltage U.sub.N is adjacent a diode 10 acting as a rectifier diode. The diode 10 conducts only when the network voltage U.sub.N is across positive than an output voltage U.sub.Z across to a smoothing capacitor 12. If the smoothing capacitor 12 is constructed sufficiently large, the power consumption from the network takes place only within a narrowly limited time on both sides of the maximum of the network voltage U.sub.N. Current peaks thereby occur whose magnitude is in principle limited only by the network impedance. Such current peaks cause undesired harmonics in the network, and lead to a flattening of the network voltage U.sub.N in the region near the voltage maximum.

Brief Summary Paragraph Right (5):
In order to reduce these undesired effects, the rectifier is conventionally not directly connected to the current network, but rather via a passive filter (not shown in FIG. 1). Such a filter limits and distributes the current consumption from the network. At the power values that are of interest here, a sufficiently dimensioned filter is large, heavy and expensive. In addition, it is expected that the relevant regulations of the electrical utility companies will become more stringent in the future, causing the required expense to increase further.

Brief Summary Paragraph Right (6):
FIG. 2 shows a known rectifier bridge circuit for a three-phase current network. Three network input terminals 20, 20', 20" are connected respectively with rectifier branches via a filter 22. Each rectifier branch contains two diodes 24, 26; 24', 26'; 24", 26" connected in series with the same polarity. The three rectifier branches are connected in parallel and with a smoothing capacitor 28. Overall, the circuit according to FIG. 2 provides an output voltage U.sub.Z which is always at least as large as the largest difference between each two phases of the three-phase current network. The negative side of the output voltage U.sub.Z is at an output terminal 30, and the positive side of the output voltage U.sub.Z is at to an output terminal 32.

Brief Summary Paragraph Right (7):
In this three-phase rectifier circuit as well, for the reasons already cited the

filter 22 causes a considerable expense.

Brief Summary Paragraph Right (8):
An object of the present invention is to provide a circuit for supplying a load with a direct voltage that has advantageous power consumption characteristics. In particular, it is an object to provide such a circuit that is more economical and/or has a smaller structural size than conventional circuits that require an expensive filter.

Brief Summary Paragraph Right (9):
The invention is based on the fundamental concept of supplying the load not only via one or more rectifier diodes, but in addition via at least one step-up converter. As used herein, the term "step-up converter" means any circuit having an inductance and a switching element which uses the turn-off voltage surge of the inductance in order to achieve an output voltage that is higher in relation to an input voltage. With such a step-up converter, it is then possible to take power from a network phase even if the voltage of this phase (in relation to the lowest potential of the other phases) is lower than the output voltage. By this means, a more uniform network loading can be achieved.

Brief Summary Paragraph Right (10):
According to the invention, the step-up converter is connected in parallel to the aforementioned diode in the current path in order to supply the load. This does not necessarily mean that these two components must be provided independently of one another. Rather, the diode can, besides its rectifier function, also serve as a component of the step-up converter.

Brief Summary Paragraph Right (11):
In preferred constructions, the step-up converter is driven according to a supply voltage at the input side. The driving signals can have a predetermined frequency and/or pulse duration, however, these parameters can also be variable and can be controlled or regulated. In a relatively simple construction, the step-up converter is activated if the supply voltage is at a predetermined minimum level, and, moreover, is below a predetermined limit value. In addition, the step-up converter can be driven dependent on the output voltage of the circuit.

Brief Summary Paragraph Right (12):
The step-up converter preferably is formed by can inductance (inductive component), a diode and a switching element. The inductance can be connected with the supply voltage via the switching element.

Brief Summary Paragraph Right (14):
The circuit contains a bridge rectifier circuit, however, alternatively the circuit can be already supplied with a pulsed direct voltage. The circuit is preferably designed for connection to a three-phase network with three phases or to an alternating voltage network with one phase and a directly grounded conductor.

Drawing Description Paragraph Right (1):
FIGS. 1 and 2, as noted above, show rectifier circuits according to the prior art.

Drawing Description Paragraph Right (2):
FIG. 3 shows a circuit diagram of the inventive circuit.

Drawing Description Paragraph Right (3):
FIGS. 4 show voltage and drive signal curves during operation of the inventive circuit.

Drawing Description Paragraph Right (4):
FIGS. 5a and 5b show voltage and current curves for a weak load and for a full load, respectively.

Drawing Description Paragraph Right (5):
FIG. 6 shows an output voltage curves of the inventive circuit under weak load and full load conditions.

Detailed Description Paragraph Right (1):
The circuits shown in FIG. 1 and FIG. 2 have already been described above. The circuit according to FIG. 3 is based on the known three-phase rectifier circuit according to FIG. 2. Here as well, three input terminals 20, 20', 20", a filter 22,

three rectifier branches each formed from two diodes 24, 26; 24', 26'; 24", 26", and a smoothing capacitor 28 connected across output terminals 30, 32 are provided. These components are likewise connected as shown in FIG. 2, and thus form a rectifier circuit for the three-phase network voltage across to the input terminals 20, 20', 20". The filter 22 is known, and contains several inductances connected in the network lines, as well as several capacitors that are connected between the network phases and to ground.

Detailed Description Paragraph Right (2):
An output voltage U.sub.Z is across a load that is formed by the smoothing capacitor 28 as well as from additional components not shown in FIG. 3. The load is supplied with power via several current paths. These current paths proceed respectively via the diodes 24, 24', 24". The circuit according to FIG. 3 can, for example, be provided in a power supply unit of a gradient amplifier. The output voltage U.sub.Z is then, for example, the intermediate circuit voltage of this power supply unit.

Detailed Description Paragraph Right (3):
A step-up converter is connected in parallel with each of three diodes 24, 24', 24". Each step-up converter includes an inductance 34, 34', 34", a diode 36, 36', 36" connected in series therewith, and a switching element 38, 38', 38". In the step-up converter arranged parallel to the diode 24, a first terminal of the inductance 34 and a first terminal of the switching element 38 are connected with the anode of the diode 36. The second terminal of the inductance 34 is connected with the anode of the diode 24, and the cathodes of the two diodes 24 and 36 are connected together. The second terminal of the switching element 38 is connected with the negative pole of the output voltage U.sub.Z, i.e. with the anodes of the three diodes 26, 26', 26" and with the output terminal 30. The two additional step-up converters are constructed correspondingly. As switching elements 38, 38', 38", MOSFETs or IGBTs or other electronic switches can be used for example.

Detailed Description Paragraph Right (4):
A control 40 is provided for the production of switching signals for the three switching elements 38, 38', 38". As input values, the control units 40 picks off the supply voltages U.sub.V, U.sub.V', U.sub.V" at to the diodes 26, 26', 26", as well as the output voltage U.sub.Z. The negative pole of the output direct voltage U.sub.Z, at the output terminal 30 serves as a common reference.

Detailed Description Paragraph Right (5):
The circuit according to FIG. 3 can be used in several operating modes, according to the characteristics to be achieved. In a particularly simple operating mode, the switching elements 38, 38', 38" are operated by the control unit 40 with a constant switching frequency of several kilohertz (for example, 20 kilohertz). This switching frequency, the pulse duration, and the size of the inductances 34, 34', 34" are matched to one another. For example, when the switching element 38 is activated, the supply voltage U.sub.V is across to the inductance 34. In this time period, a current builds up in the inductance 34. When the switching element 38 is turned off, there arises a turn-off voltage surge. If the turn-off voltage is greater than U.sub.Z, it is across to the load via the diode 36. By this means, the energy stored in the inductance 34 is provided to the load.

Detailed Description Paragraph Right (6):
As a result, by means of this switching arrangement it is possible to take the required power much more uniformly than with a simple rectifier circuit. If, in an embodiment, the switch-on time of the switching elements 38, 38', 38" and the switching frequency are kept constant, the current consumption of a step-up converter from a network line is linear to the respective current network voltage. This corresponds to a purely ohmic characteristic.

Detailed Description Paragraph Right (7):
In alternative embodiments, the step-up converters are activated only intermittently. In particular, embodiments are provided in which a step-up converter operates only when the supply voltage U.sub.V, U.sub.V', U.sub.V" , at to this step-up converter is smaller than a predetermined threshold voltage U.sub.S. The threshold voltage U.sub.S can in particular be defined as a fraction of a peak voltage U of the current network.

Detailed Description Paragraph Right (8):
Such an embodiment is illustrated in FIG. 4 Diagram a shows sinusoidal voltage curves of the three-phase network phases U.sub.L, U.sub.L', U.sub.L" in a

representation symmetrical to a null voltage. In diagram b, the same voltage curves as in diagram a are shown, but as a reference voltage for each phase the respective lower value of the other two phases is always used. This corresponds to the supply voltages U.sub.V, U.sub.V', U.sub.V" of FIG. 3. Diagram c shows, as examples, the supply voltage U.sub.V, the threshold voltage U.sub.S and the peak voltage U.

Detailed Description Paragraph Right (9):
Diagram d shows the switching signals produced by the control units 40 for the switching element 38. From diagram d, it can be seen that the step-up converter allocated to the diode 24 is active only when the supply voltage U.sub.V is genuinely greater than 0 volts but is smaller than the threshold voltage U.sub.S. This is also true for the other two step-up converters, as is shown in diagram e for the switching signal supplied to the switching element 38' and in diagram f for the switching signal supplied to the switching element 38".

Detailed Description Paragraph Right (11):
In all specified embodiments, the power of the step-up converters can be limited to a part of the overall required power. For Example, given a power supply unit with 20 kW power, the three step-up converters can each be designed at 3 kW. In this case, the current consumption takes place only via the step-up converters, as long as the power consumption of the load is smaller than the efficiency thereof.

Detailed Description Paragraph Right (12):
Weak load operation is shown schematically in FIG. 5a. The broken lines 42 indicate the flow of current through the step-up converters. During the negative half wave of the network phase U.sub.L, the supply to the load of course does not take place via the step-up converter allocated to the diode 24, but rather via the other two step-up converters.

Detailed Description Paragraph Right (13):
Given a higher power requirement, current over the normal rectification is additionally consumed. This current consumption takes place (as already depicted above) only during the maxima of the input voltages, i.e., at inherently undesirable times. However, since this current consumption relates only to the additionally required power, the current strengths that occur are smaller than without a step-up converter. For this reason, the filter 22 can be dimensioned relatively small. FIG. 5b shows such a full load operation, whereby the broken lines 44 indicate the peak load supplying by means of the rectifier diodes. The activation intervals of the step-up converters shown in FIG. 5a and FIG. 5b deviate from those according to FIG. 4d to FIG. 4f.

Detailed Description Paragraph Right (14):
In addition, in all embodiments specified herein, a suitable no-load voltage regulation of the step-up converters is provided. FIG. 6 shows the output voltage U.sub.Z in a no-load or weak load operation (left half) and in a full load operation (right half). In no-load operation, the control means 40 ensures that a maximum output voltage U.sub.Z is not exceeded. For this purpose, for example the pulse width of the drive signals for the switching elements 38, 38', 38" can be reduced, or the step-up converters can all be switched off together. In full load operation, the step-up converters influence the output voltage U.sub.Z only slightly, so that a similar ripple occurs as in the three-phase rectifier bridge shown in FIG. 2.

Detailed Description Paragraph Right (15):
In further versions the frequency and/or the pulse duration (duty cycle) and/or other characteristics of the drive signals can be modified (regulated) according to the momentary operating state. By means of such control or regulation, particularly advantageous characteristics can be achieved with respect to current consumption and/or the output voltage and/or the load distribution within the circuit.

Detailed Description Paragraph Right (16):
In further embodiments, the control units 40 drives, the switching elements 38, 38', 38" with a common clock. This results in a simpler circuit design. In alternative embodiments, clock signals offset to one another are provided for the switching elements 38, 38', 38", with the effective clock frequency being increased and the ripple is reduced.

CLAIMS:

1. A circuit for supplying a load with a direct voltage, comprising:

a three-phase rectifier bridge circuit comprising three rectifier branches, wherein each of said rectifier branches supplies a respective supply voltage to a respective current path for supplying said load,

three step-up converters, each of said step-up converters being connected in parallel to a respective diode, each of said diodes being arranged in a respective one of said current paths for supplying said load, and

a control unit connected to said step-up converters and driving said step-up converters according to predetermined criteria for supplying said load at least partially through said step-up converters.

2. A circuit as claimed in claim 1, wherein said control unit drives each of said step-up converters dependent on a respective one of said supply voltages.

3. A circuit as claimed in claim 2, wherein said control unit activates each step-up converter only when said respective one of said supply voltages is lower than a predetermined threshold voltage.

4. A circuit as claimed in claim 1, wherein each of said step-up converters comprises an inductive component, and a diode connected in series with said inductive component, and a switching element operated by said control unit for connecting said inductive component to said respective one of said supply voltages.

5. A circuit as claimed in claim 1, wherein said control unit is adapted for limiting an overall output voltage of said circuit to a predetermined maximum value under an operation selected from the group consisting of a no-load condition and a weak-load condition.

6. A circuit as claimed in claim 1, wherein said load comprises a gradient amplifier.

7. A circuit for supplying a load with a direct voltage, comprising:

a bridge rectifier comprising a plurality of pairs of diodes, each of said pairs of diodes forming a respective rectifier branch, wherein each of said rectifier branches supplies a respective supply vo!tage to a respective current path for supplying said load,

a step-up converter comprising an inductive component and a diode connected in series with said inductive component,

a control unit connected to said step-up converter for driving said step-up converter according to predetermined criteria for supplying said load at least partially through said step-up converter, wherein

said inductive component and said diode of said step-up converter are connected directly in parallel to one of said diodes of said bridge rectifier.

8. A circuit as claimed in claim 7, wherein said control unit drives said step-up converter dependent on that one of said supply voltages that is connected across that one of said current paths that is associated with said step-up converter.

9. A circuit as claimed in claim 8, wherein said control unit activates said step-up converter only when said one of said supply voltages is lower than a predetermined threshold voltage.

10. A circuit as claimed in claim 7, wherein said step-up converter further comprises a switching element through which said inductive component is connectable to that one of said supply voltages that is connected across that one of said current paths that is associated with said step-up converter.

11. A circuit as claimed in claim 7, wherein said control unit is adapted for limiting an overall output voltage of said circuit to a predetermined maximum value under an operation selected from the group consisting of a no-load condition and a weak-load condition.

12. A circuit as claimed in claim 7, wherein said load comprises a gradient

amplifier.

13. A circuit for supplying a load with a direct voltage, comprising:

a three-phase bridge rectifier that comprises:

a first rectifier branch comprising a first pair of diodes and supplying a first supply voltage to a first current path for supplying said load,

a second rectifier branch comprising a second pair of diodes and supplying a second supply voltage to a second current path for supplying said load, and

a third rectifier branch comprising a third pair of diodes and supplying a third supply voltage to a third current path for supplying said load,

a first step-up converter comprising a first inductive component and a first diode connected in series with said first inductive component, said first inductive component and said first diode being connected directly in parallel to one diode of said first pair of diodes of said bridge rectifier,

a second step-up converter comprising a second inductive component and a second diode connected in series with said second inductive component, said second inductive component and said second diode being connected directly in parallel to one diode of said second pair of diodes of said bridge rectifier,

a third step-up converter comprising a third inductive component and a third diode connected in series with said third inductive component, said third inductive component and said third diode being connected directly in parallel to one diode of said third pair of diodes of said bridge rectifier, and

a control unit connected to said first, second and third step-up converters and driving said first, second and third step-up converters according to predetermined criteria for supplying said load at least partially through said first, second and third step-up converters.

14. A circuit as claimed in claim 13, wherein said control unit drives said first, second and third step-up converters dependent on the respective one of said first, second and third supply voltages.

15. A circuit as claimed in claim 14, wherein said control unit activates said first, second and third step-up converters only when said respective one of said first, second and third supply voltages is lower than a predetermined threshold voltage.

16. A circuit as claimed in claim 13, wherein said first step-up converter further comprises a first switching element through which said first inductive component is connectable to said first supply voltage, and said second step-up converter further comprises a second switching element through which said second inductive component is connectable to said second supply voltage, and said third step-up converter further comprises a third switching element through which said third inductive component is connectable to said third supply voltage.

17. A circuit as claimed in claim 13, wherein said control unit is adapted for limiting an overall output voltage of said circuit to a predetermined maximum value under an operation selected from the group consisting of a no-load condition and a weak-load condition.

18. A circuit as claimed in claim 13, wherein said load comprises a gradient amplifier.

DOCUMENT-IDENTIFIER: US 6140873 A
TITLE: Power amplifier with soft switching and multilevel switching cells

Abstract Paragraph Left (1):
A power amplifier for delivering large currents as well as high voltages of the order of some hundreds of amperes and 1000 or more volts, notably for MRI. The amplifier is constructed as a multilevel inverter in order to comply with the requirement of high voltages while utilizing transistors capable of withstanding lower voltages only. The amplifier is arranged for soft switching, so that the switching losses at said large currents are limited.

Brief Summary Paragraph Right (2):
The invention relates to a power amplifier for delivering large currents as well as high voltages.

Brief Summary Paragraph Right (4):
Amplifiers of this kind can be used for a large variety of applications. Even though the invention will be described on the basis of an application in the magnetic resonance imaging (MRI) technique, notably for driving the gradient coils of an MRI apparatus, the application of the invention is by no means restricted to such a technical field.

Brief Summary Paragraph Right (5):
MRI systems utilize power amplifiers for driving the coils which generate so-called gradient fields. Such gradient fields are magnetic fields having a strength which varies linearly in a given co-ordinate direction in order to define the location of the image to be formed by means of the MRI apparatus by addition of this gradient field to a strong steady, uniform field. To this end, current pulses of an intensity of the order of magnitude of more than 600 A at a voltage of the order of magnitude of more than 500 V are applied to the gradient coils, the rise time of the pulses being of the order of magnitude of 0.2 ms whereas the pulse duration is of the order of magnitude of from 1 ms to 10 ms.

Brief Summary Paragraph Right (6):
Thus, in the context of the present invention large currents are to be understood to mean currents of the order of magnitude of several hundreds of amperes, and high voltages are to be understood to mean voltages of the order of magnitude of one thousand volts or more.

Brief Summary Paragraph Right (7):
Nowadays there is a tendency towards shorter rise times with larger maximum currents so as to reduce the time required for the acquisition of MRI information for the formation of an MRI image; this offers advantages inter alia in respect of image sharpness and also in respect of imaging of moving objects. Because the gradient coils exhibit an inductive behavior to the driving amplifier, a higher voltage is required so as to achieve a shorter rise time of the pulses. Increasing the currents and the voltages to be supplied by the amplifier, in combination with a shorter rise time, gives rise to problems concerning the electronic components in the amplifier. Losses in the semiconductor components cause a significant development of heat, giving rise to cooling problems. These problems can be mitigated partly by using a switched inverter, that is to say an amplifier whose transistors which carry the output current are switched to be either completely turned on or completely turned off. Switching to the turned-off or turned-on state is controlled by means of a pulse width modulated (PWM) signal. The output voltage of the inverter is then determined by the duty cycle of the PMW signal.

Brief Summary Paragraph Right (8):
Other problems are encountered when the desired output voltage is increased and/or the desired rise time is reduced: the desired voltage may be so high that no transistors are available or, should they be available, they have a stray capacitance which is so high that the PWM switching frequency (of the order of magnitude of 20 kHz) required for the relevant application can no longer be reached. Moreover, in the case of a high supply voltage the voltage transients at the output of the amplifier, but preceding the output low-pass filter, in response to the switching of the amplifier transistors would become so high that the higher harmonic content of the output signal would become so high that the output low-pass filter would have to satisfy very severe requirements. The latter problems can be partly mitigated by using a switched amplifier of the multilevel type (multilevel inverter).

Brief Summary Paragraph Right (9):
In an inverter of this type the total voltage is distributed between two or more series-connected transistors, means being provided so as to prevent the total voltage from still being present across a single transistor due to, for example inequalities of the transistors (for example, due to individual spreads caused by manufacturing tolerances). Such means consist of one or more capacitors which are connected parallel to a part of the series connection of the transistors and always carry a more or less constant fraction of the total voltage present across the series connection of the transistors. Inverters of this kind are known per se, for example from an article in EPE Journal, Vol. 3, No. 2, June 1993, pp. 99-106, entitled "Imbricated cells Multi-Level Voltage Source Inverters for High Voltage Applications".

Brief Summary Paragraph Right (10):
In these known multilevel inverters use can thus be made of transistors (generally semiconductor elements), each of which has a breakdown voltage which is lower than the total voltage present across the circuit, and hence also lower than the output voltage of the circuit. In this known circuit, however, the problem in respect of the power losses in the semiconductor components and the associated cooling problems are not solved completely, notably not in respect of the required high PWM switching frequencies. These power losses consist of switching losses and conduction losses due to the resistance of the material of the various components.

Brief Summary Paragraph Right (11):
Due to the high output voltages and the high switching frequency, the switching losses usually are predominant in amplifiers for high powers and high PWM switching frequencies. Such switching losses occur because the switching transistor switches over from the turned-on to the turned-off state or vice versa. In the turned-on state the current through the transistor has a given value, but the voltage across the transistor is substantially zero or very small in any case (for example, 0.5 V); in the turned-off state the voltage across the transistor has a given value, but the current across the transistor is practically zero. During the switching-over from one state to the other, however, a product of current and voltage occurs; this implies power dissipation.

Brief Summary Paragraph Right (12):
It is known per se to reduce switching losses by means of a so-called "soft switching" technique. When this technique is used, the instant of the transition from the turned-on state to the turned-off state or vice versa (the switching) is chosen in such a manner that either the current through the switch is zero or practically zero ("Zero Current Switching") or the voltage across the switch is zero or practically zero ("Zero Voltage Switching"). Thus, the product of current and voltage is substantially zero in both cases. Inverters operating with such a switching mode are known per se, for example from an article in "Conference Record of the IEEE Industry Application Society Annual Meeting", 1990, Vol. 2, pp. 1228-1235, entitled "The Auxiliary Resonant Commutated Pole Converter". The inverters disclosed in the latter article, however, are not of the multilevel type, so that the described problems in respect of the high voltages are not solved.

Brief Summary Paragraph Right (13):
It is an object of the invention to provide a power amplifier of the inverter type for delivering large currents as well as high voltages, which amplifier utilizes semiconductor switches having a breakdown voltage which is lower than the supply voltage and involves only slight switching losses occur. A power amplifier of this

kind includes a cascade of multilevel switching cells, each multilevel switching cell including an input and an output and being provided with two controllable switches, with a respective diode which is connected antiparallel thereto, said diodes being connected in mutually opposed forward directions, each time one end of the two switches constituting one of the input terminals of the switching cell and the other ends of the two switches forming the output terminals of the switching cell, said switching cells forming a cascade in that the output terminals of a preceding switching cell are connected to the input terminals of a subsequent switching cell, a capacitor being connected between said interconnected input terminals and output terminals and a power supply source being connectable to said cascade of switching cells, said amplifier also including an inductive element one end of which is connected to the output of the amplifier, and at least two controllable switches which are connected to the other end of the inductive element, a first one of said switches being connected to a point carrying a voltage which is higher than the output voltage of the amplifier whereas a second switch is connected to a point carrying a voltage which is lower than the output voltage of the amplifier.

Brief Summary Paragraph Right (14):
In the cited article "Imbricated cells . . . etc.", notably in FIG. 4 thereof, each multilevel switching cell consists of two associated transistors with a diode connected antiparallel thereto. In this context an "antiparallel connected diode" is to be understood to mean a diode which is connected parallel to the main current path of the transistor and whose forward direction opposes that of the main current path of the transistor. Each of the controllable switches is formed by a respective transistor whose base constitutes the control input. The input of such a multilevel switching cell is formed by two terminals, the first of which is formed by the junction of the cathode of a diode and the collector of the associated transistor, the second terminal being formed by the junction of the anode of the other diode and the emitter of the associated transistor. The output of such an element is formed by two terminals, the first of which is formed by the junction of the anode of the first diode and the emitter of the first transistor whereas the second terminal is formed by the junction of the cathode of the other diode and the collector of the associated transistor.

Brief Summary Paragraph Right (15):
Between the interconnected input terminals and output terminals there is connected a capacitor which is and remains charged during operation in such a manner that across this capacitor there is present a voltage which amounts to a substantially fixed fraction of the supply voltage, i.e. the voltage originating from the power supply source to be connected. Consequently, not the full supply voltage is present across each transistor and in order to build a switched power supply intended to form a power amplifier it suffices to use transistors having a breakdown voltage which is lower than the input voltage of the amplifier to be switched. For example, in the case of a cascade comprising two stages, approximately half the supply voltage is present across said capacitor, so that in all cases no more than approximately half the supply voltage will be present across each transistor. If the number of stages is larger, a lower fraction will be present across each of the capacitors, so that for each transistor also a lower fraction of the input voltage remains.

Brief Summary Paragraph Right (16):
In order to solve said problems concerning the power losses (so the dissipation in the switching transistors) due to the high output voltages, in accordance with the invention a capacitor is connected parallel to each controllable switch, the amplifier also being provided with an inductive element, one end of which is connected to the output of the amplifier, and with at least two controllable switches which are connected to the other end of the inductive element, a first resonant switch of said switches being connected to a point carrying a voltage which is higher than the

Brief Summary Paragraph Right (17):
output voltage of the amplifier whereas a second resonant switch is connected to a point carrying a voltage which is lower than the output voltage of the amplifier.

Brief Summary Paragraph Right (18):
These steps ensure a resonant switching procedure for the switching transistors, so that the instant of switching of these transistors can be chosen in such a manner that at that instant the voltage thereacross or the current therethrough is zero. A resonant switching procedure is to be understood to mean a procedure in which such a

currentless or voltageless state is reached in that a resonant circuit is formed by the capacitors, connected parallel to the switches, and said inductive element. Said switches, in this case called resonant switches, control the current distribution of the current through the inductive element in such a manner that the desired currentless or voltageless state is obtained at the desired instants. Thus, the invention innovatively combines the multilevel inverter technique with the soft switching technique.

Brief Summary Paragraph Right (19):
The power amplifier in an embodiment of the invention is provided with a third controllable resonant switch which is connected to the other side of the inductive element and to a point carrying substantially half the supply voltage. This offers a further refinement of the voltage with which the current through the inductive element is switched so that the desired zero level of the current or the voltage is reached faster; this step can also be taken to ensure that the power dissipation in the resonant switches is reduced because the current or voltage to be switched is thus lower.

Brief Summary Paragraph Right (20):
In a further embodiment of the invention a capacitor is connected parallel to each of the resonant switches in the power amplifier. This step also yields "soft switching" of the resonant switches, offering an additional gain in respect of the dissipation of the amplifier, notably in the case of high powers.

Brief Summary Paragraph Right (21):
In another embodiment of the invention, the point with substantially half the supply voltage in the power amplifier is realized by voltage division by means of two capacitors connected between the points whereto a power supply source can be connected. It would be feasible to derive half the supply voltage from a separate power supply apparatus, or by means of a resistance voltage divider. Both feasible solutions have their own drawback: separate power supply apparatus are expensive and comparatively vulnerable, and resistors dissipate power. The step according to the invention, however, ensures that only little power is lost whereas the desired point with half the supply voltage can still deliver current with a low impedance. Because these capacitors participate in the resonant process, they are charged or discharged during operation in such a manner that the junction of the two capacitors is always driven to half the supply voltage.

Brief Summary Paragraph Right (22):
The power amplifier in another embodiment of the invention is provided with a cascade of n multilevel switching cells and with n supply points, the i.sup.th supply point delivering a voltage substantially equal to i/n times the voltage from the power supply source, the amplifier furthermore being provided with n controllable resonant switches which are connected to the other side of the inductive element, the i.sup.th switch of the resonant switches being connected to the i.sup.th supply point. As a result of this step, the principle of the invention is further generalized to an n-level amplifier whose resonant process is driven from n equidistant voltages. The amount of power lost is thus further minimized and the ripple on the output signal of the amplifier becomes much smaller, so that the output low-pass filter need only satisfy less severe requirements.

Brief Summary Paragraph Right (23):
The power amplifier in a further embodiment of the invention is provided with a capacitor which is connected parallel to each of the resonant switches. This step ensures that soft switching of the resonant switches is also achieved in the generalized form of the power amplifier, yielding an additional gain in respect of the dissipation of the amplifier, notably in the case of high powers.

Drawing Description Paragraph Right (2):
FIG. 1 shows diagrammatically the general construction of a magnetic resonance apparatus;

Drawing Description Paragraph Right (3):
FIG. 2 shows a first embodiment of the power amplifier according to the invention;

Drawing Description Paragraph Right (4):
FIG. 3 shows, in order to illustrate the principle of soft switching, an amplifier which is not constructed as a multilevel inverter;

Drawing Description Paragraph Right (5):
FIG. 4 shows a second embodiment of the power amplifier according to the invention.

Detailed Description Paragraph Right (1):
The magnetic resonance imaging apparatus which is diagrammatically shown in FIG. 1 includes a first magnet system 1 for generating a steady magnetic field B, a second magnet system 3 (the gradient coil system) for generating magnetic gradient fields, a power amplifier 7 for the gradient coil system 3, and a power supply source 5 for the first magnet system 1. An RF coil 9 serves to generate an RF magnetic alternating field; to this end it is connected to an RF transmitter device which includes an RF source 11. The RF coil 9 can also be used for the detection of spin resonance signals generated by the RF transmitter field in an object to be examined (not shown); to this end, this coil is connected to an RF receiver device which includes a signal amplifier 13. The output of the signal amplifier 13 is connected to a detector circuit 15 which is connected to a central control device 17. The central control device 17 also controls a modulator 19 for the RF source 11, the power amplifier 7 and a monitor 21 for image display. An RF oscillator 23 controls the modulator 19 as well as the detector 15 processing the measuring signals. For the cooling of the magnet coils of the first magnet system 1 there is provided a cooling device 25 which includes cooling ducts 27. The RF coil 9, being arranged within the magnet systems 1 and 3, encloses a measuring space 29 which, in the case of an apparatus for medical diagnostic measurements, is large enough to accommodate a patient to be examined or a part of the patient to be examined, for example the head and the neck. Thus, a steady magnetic field B, gradient fields for the selection of object slices, and a spatially uniform RF alternating field can be generated in the measuring space 29. The RF coil can combine the functions of transmitter coil and measuring coil, in which case a separating circuit 14 is provided so as to separate the forward and return signal traffic. However, different coils can also be used for these two functions; for example, surface coils then act as measuring coils. If desired, the coil 9 may be enclosed by an RF field shielding Faraday cage 31.

Detailed Description Paragraph Right (2):
FIG. 2 shows a power amplifier 7 according to the invention as can be used for the power supply of the gradient coil system 3 shown in FIG. 1. The power amplifier includes a cascade of n multilevel switching cells (34), only the switching cells 34-1, 34-2 and 34-n thereof being shown in the Figure. All switching cells have the same construction; therefore, the construction of the switching cells will be described on the basis of one switching cell, i.e. the switching cell 34-1. Two controllable switches 36 and 38 are connected between the input 44 and the output 46 of the switching cell. These controllable switches are preferably constructed as a semiconductor element of a suitable form, for example a thyristor or an IGBT transistor (Insulated Gate Bipolar Transistor), the latter being particularly suitable for switching large currents at high voltages. A diode 40, 42 is connected antiparallel to each of the transistors 36 and 38, which means that this diode is connected parallel to the main current path of the associated transistor; however, its forward direction opposes that of the transistor. The two diodes 40 and 42 are also connected so as to have a mutually opposed forward direction. Furthermore, a respective capacitor 52, 54 is connected parallel to each controllable switch 36, 38. The input 44 of the switching cell 34 thus consists of two connection terminals, one of which is formed by one of the connection points of said parallel connected elements 36, 40 and 54 whereas the other input terminal is formed by one of the connection points of said parallel connected elements 38, 42 and 52. The output 46 of the switching cell 34 also consists of two connection terminals, one of which is formed by the other connection point of said parallel connected elements 36, 40 and 54 whereas the other output terminal is formed by the other connection point of said parallel connected elements 38, 42 and 52.

Detailed Description Paragraph Right (3):
The switching cells 34-1 to 34-n are combined so as to form a cascade by connecting the output terminals 46 of a preceding switching cell (for example, 34-1) to the input terminals 44 of a subsequent switching cell 34-2. The input 44 is connected to the output 46 by interconnecting the corresponding connection terminals of the input and the output. A capacitor 48 is connected between the set of terminals consisting of the input terminal and the corresponding output terminal thus interconnected on the one side and the other set of terminals on the other side. A power supply source 50 is also connected to the cascade of switching cells.

Detailed Description Paragraph Right (4):

The amplifier 7 is also provided with a self-inductance 58, one side of which is connected to the output 46-n of the amplifier. A parallel connection of three switches 60-1, 60-2 and 60-3 is connected to the other side of the self-inductance 58. Hereinafter these switches will be referred to as resonant switches because of their function (to be described hereinafter) concerning the resonant phenomenon during the soft switching of the transistors of the power amplifier which carry the output current. The first (60-1) of these three resonant switches is connected to the positive side of the supply source 50, so to a point carrying a voltage which is higher than the output voltage of the amplifier (i.e. the voltage at the output 46-n); the second switch 60-2 is connected to the negative side of the supply source 50, so to a point carrying a voltage which is lower than the output voltage of the amplifier. Between the positive side and the negative side of the power supply source 50 there is connected a series connection of two identical capacitors 66 and 68; the connection point 62 of this series connection thus constitutes a point carrying substantially half the supply voltage. The third resonant switch 60-3 is connected between the self-inductance 58 and the connection point 62.

Detailed Description Paragraph Right (5):
A load 70 is connected to the output 46-n of the amplifier 7. When the amplifier is used in an MRI apparatus, the gradient coil to be fed forms part of said load. However, in a "switched inverter" a low-pass filter for removing the switching frequency from the supply signal is customarily connected between the output of the amplifier and the impedance to be fed. In this case it is assumed that this low-pass filter forms part of the load 70.

Detailed Description Paragraph Right (6):
It is to be noted that the amplifier shown in FIG. 2 could constitute only one half of the overall amplifier whereby the gradient coil is driven. This is the case when the load 70 is to be supplied with a current in two directions. In that case an identical amplifier section is situated to the other side of the load 70, so that the overall amplifier is formed by two half bridges, one of which is shown in FIG. 2. However, the foregoing does not have any bearing on the principle of the invention.

Detailed Description Paragraph Right (7):
In order to clarify the soft switching in a switched amplifier, such soft switching will first be illustrated with reference to FIG. 3, which shows a switched amplifier which is not of the multilevel type, i.e. an amplifier in which the total voltage is not distributed between two or more series-connected transistors. Thus, therein the total voltage is present across one transistor only.

Detailed Description Paragraph Right (8):
FIG. 3 shows a so-called half bridge for feeding the load 70. In comparison with FIG. 2, in this half bridge the transistors 36-1 to 36-n and 38-1 to 38-n have been replaced by the transistors 36 and 38, respectively; the diodes 40-1 to 40-n and 42-1 to 42-n have been replaced by the diodes 40 and 42, respectively, and the capacitors 52-1 to 52-n and 54-1 to 54-n have been replaced by the capacitors 52 and 54, respectively. The combination formed by the resonant switches 60-1, 60-2 and 60-3 and the capacitors 64-1, 64-2 and 64-3 has been replaced by the circuit 72. The circuit 72 consists of two parallel branches, the first parallel branch consisting of a series connection of two transistors 74 and 76 which are connected so as to have opposed forward directions whereas, the second parallel branch consists of a series connection of two diodes 78 and 80 which are also connected so as to have opposed forward directions.

Detailed Description Paragraph Right (9):
Three situations will be considered in order to illustrate the soft switching in the circuit shown in FIG. 3: (I) switching over from the diode 42 conductive to the transistor 36 conductive; (II) switching over from the transistor 36 conductive to the diode 42 conductive in the case of small currents; (III) switching over from the transistor 36 conductive to the diode 42 conductive in the case of large currents.

Detailed Description Paragraph Right (10):
In the situation I it is assumed that the transistors 36 and 38 and the diode 40 are not conductive ("off"), that the diode 42 is conductive ("on"), and that the transistor 36 is turned on ("is switched on"). In this starting situation a current flows through the diode 42 to the load 70 via the output 46. In order to start the switching process, the transistor 76 is switched on. As a result, half the supply voltage of the point 62 appears across the self-inductance 58. The current through

the self-inductance 58 then increases linearly in time. During this period the transistor 38 is switched on but it does not conduct current while the current through the diode 42 decreases linearly. The current through the load 70 is then assumed to be constant.

Detailed Description Paragraph Right (11):
When the current through the self-inductance 58 becomes larger than the current through the load 70, the so-called boost phase commences. The current through the diode 42 becomes zero (diode 42 is switched off) and the current through the transistor 38, being the boost current, then becomes equal to the current through the self-inductance 58 minus the current through the load 70. The boost current through the transistor 38 increases linearly in time, so that the duration of the boost phase (and hence the value of the boost current) can be controlled with a simple time delay. It is to be noted that the direction of the recovery current in the diode 42 is such that this current also adds boost energy and hence contributes to the switching process.

Detailed Description Paragraph Right (12):
When the boost current reaches the desired value, the transistor 38 is switched off so that the resonant switching phase commences. The voltage at the output 46 abandons the value of the negative supply voltage and swings to the positive supply voltage because the current flowing through the transistor 38 flows to the resonant capacitors 52 and 54 during switching off. If the transistor 38 still has a tail current, switch-off losses will occur. During this phase the current through the self-inductance 58 consists of a half period of a sinusoidal current superposed on a DC load current.

Detailed Description Paragraph Right (13):
When the voltage at the output 46 tends to exceed the positive supply voltage, the so-called clamping phase commences. The diode 40 is then polarized in the forward direction, so that the output 46 is connected to the positive supply voltage. At that instant the transistor 36 is switched on without switching losses. The residual boost energy still present in the self-inductance 58 then disappears to the capacitors 66 and 68 because the current through the self-inductance 58 decreases linearly as imposed by the half supply voltage at the point 62.

Detailed Description Paragraph Right (14):
When the current through the self-inductance 58 becomes smaller than the current through the load 70, the so-called ramp down phase commences; the current through the self-inductance 58 still decreases during this phase. The current through the load 70 is then taken over by the transistor 36.

Detailed Description Paragraph Right (15):
The switching procedure ends when the current through the self-inductance 58 becomes zero and the transistor 76 is switched off.

Detailed Description Paragraph Right (16):
In the situation II (switching over from the transistor 36 switched on to the diode 42 switched on for small currents) it is assumed that the transistor 36 is switched on, that the other transistors and diodes are not switched on, and that the transistor 36 is switched off so that the diode 42 takes over the current.

Detailed Description Paragraph Right (17):
In order to start the switching process, the transistor 74 is switched on. As a result, half the supply voltage as present at the point 62 will appear across the self-inductance 58. The boost phase of the switching process then commences immediately, so that the current through the self-inductance 58 increases linearly in time. This boost current again serves to start the resonant cycle by supplying a sufficient amount of energy for bridging the losses occurring during the switching phase. During this boost phase the boost current plus the current through the load 70 flows through the transistor 36, so that the current through this transistor is briefly increased. (It is to be noted that this procedure holds for small load currents, i.e. when the current through the load 70 is much smaller than the maximum current through the transistor 36, so that an increase of the current does not lead to additional loading of the switching transistor.)

Detailed Description Paragraph Right (18):
When the boost current reaches the desired value, the transistor 36 is switched off so that the resonant switching phase commences. The voltage at the output 46

abandons the value of the positive supply voltage and swings to the negative supply voltage; the current flowing through the transistor 36 during switching off is then taken over by the resonant capacitors 52 and 54. During this phase the current through the self-inductance 58 consists of a half period of a sinusoidal current superposed on the boost current.

Detailed Description Paragraph Right (19):
The so-called clamping phase commences when the voltage at the output 46 tends to drop below the negative supply voltage. As a result, the diode 42 is polarized in the forward direction, so that the output 46 is connected to the negative supply voltage. At that instant the transistor 38 is switched on without switching losses. The residual boost energy still present in the self-inductance 58 disappears to the capacitors 66 and 68 because the current through the self-inductance 58 decreases linearly as imposed by the half supply voltage at the point 62.

Detailed Description Paragraph Right (20):
The switching procedure ends when the current through the self-induction 58 becomes zero and the transistor 74 is switched off. The full current through the load 70 then flows through the diode 42.

Detailed Description Paragraph Right (21):
In the situation III (switching over from the transistor 36 swiched on to the diode 42 switched on for large currents) it is assumed that the transistor 36 is conductive, that the other transistors and diodes are not conductive, and that the transistor 36 is switched off so that the diode 42 takes over the current.

Detailed Description Paragraph Right (22):
The procedure for the situation III deviates significantly from that for the situation II, because the circuit 72 is no longer used. In this case the current through the load suffices to drive the output voltage from the positive supply voltage value to the negative value. When the current through the transistor 36 is larger than a predetermined threshold value, the transistor 74 is not switched on but the transistor 36 is switched off directly.

Detailed Description Paragraph Right (23):
The voltage at the output 46 decreases linearly in time until it drops below the negative supply voltage. The diode 42 is then polarized in the forward direction, so that it takes over the full load current. This ends the switching procedure.

Detailed Description Paragraph Right (24):
The operation of the power amplifier according to the invention will be described in detail with reference to FIG. 4. This Figure shows a power amplifier according to the invention which is constructed in the form of a multilevel inverter with soft switching. The soft switching in this amplifier is used for switching over the power transistors as well as for switching over the transistors for controlling the resonant elements for realizing the soft switching.

Detailed Description Paragraph Right (25):
FIG. 4 shows a version of the power amplifier shown in FIG. 2. The transistors 100, 102, 104 and 106 in FIG. 4 correspond to the transistors 36-1, 36-2, 38-2 and 38-1, respectively; the diodes 110, 112, 114 and 116 in FIG. 4 correspond to the diodes 40-1, 40-2, 42-2 and 42-1, respectively, and the capacitors 120, 122, 124 and 126 in FIG. 4 correspond to the capacitors 54-1, 54-2, 52-2 and 52-1, respectively. The capacitor 96 in FIG. 4 corresponds to the capacitor 48-1 of FIG. 2.

Detailed Description Paragraph Right (26):
The combination of the resonant switches 60-1, 60-2 and 60-3 and the capacitors 64-1, 64-2 and 63-3 of FIG. 1 has been replaced by the circuit 82. The circuit 82 consists of three parallel branches; the first parallel branch consists of a series connection of two transistors 84 and 86 which are connected in the same forward direction and constitute the resonant switches; the second parallel branch consists of a series connection of two diodes 88 and 90 which are connected in the same forward direction and the third parallel branch consists of a series connection of two resonant capacitors 92 and 94. The soft switching process in the power amplifier shown in FIG. 4 will be described on the basis of a switching example, in this case being the switching over from the diode 114 to the transistor 102. This switching example is also representative of other switching situations. It is assumed that the current through the load 70 is constant during switching over.

Detailed Description Paragraph Right (27):
It is also assumed that the transistor 100 and the diode 114 are conductive, so that the output current flows through said elements. The output current then also flows through the capacitor 96. The capacitor 96 serves to maintain approximately half the supply voltage between the emitter of the transistor 100 and the collector of the transistor 106, so that no more than approximately half the supply voltage can ever arise across each of the transistors 100, 102, 104, and 106. The transistor 104 is also switched on for reasons to be explained hereinafter, but for the time being no current will flow therethrough.

Detailed Description Paragraph Right (28):
The switching process is started in that the transistor 84 is switched on. As a result, the positive supply voltage appears across the self-inductance 58, so that the current through the self-inductance 58 increases linearly in time. A current then flows from the positive side of the power supply source 50 through successively the transistor 84, the self-inductance 58, the diode 114, the capacitor 96 and the diode 110 and back to the power supply source 50; the current originating from the diode 114 is also branched to the load 70. Even though it looks in FIG. 3 as if the diode 114 is connected in the reverse direction and hence cannot conduct said current, said current in reality has the appearance of a decrease of the output current which already flows through the diode 114 and passes through the diode in the forward direction.) When the current through the self-inductance 58 tends to become larger than the current through the load 70, the current through the diode 114 becomes equal to zero and is taken over by the transistor 104 which thus switches over in response to the current zero. It is also necessary to sustain a current through the transistor 104, because the output voltage at the point 46 must be raised from half to the full supply voltage. This transition is enabled by the charging and discharging of the capacitors 122 and 124, respectively; this takes place by way of the inductive energy stored in the self-inductance 58 which, therefore, must be sufficient so as to increase the voltage across said capacitors to half the supply voltage.

Detailed Description Paragraph Right (29):
When a sufficient amount of boost energy has been stored in the self-inductance 58 so as to charge and discharge the capacitors 122 and 124, respectively, to such an extent that the voltage jump from half to full supply voltage can be made at the output 46, the transistor 104 is switched off. The boost energy stored in the self-inductance 58 is then used to discharge the capacitor 122 and to charge the capacitor 124. A current then flows through the transistor 84 and the self-inductance 58, which current is subsequently branched between said capacitors and the load.

Detailed Description Paragraph Right (30):
The resonant state is terminated when the voltage across the capacitor 122 has become zero and the diode 112 takes over the inductor current, so that the voltage across the capacitor 124 is maintained at half the supply voltage. When the voltage across the capacitor 122 has become zero, the current through the self-inductance 58 is also maintained at the value of that instant. After the resonant switching over, the boost current through the self-inductance 58 continues to flow through the transistor 84 and the diodes 112 and 110. This freewheeling current is sustained for as long as the transistor 84 remains conductive.

Detailed Description Paragraph Right (31):
The transistor 84 is switched off at the instant of occurrence of said freewheeling current situation. As a result, the current through the self-inductance 58 is very quickly taken over by the diode 90. During this phase a counter voltage amounting to the supply voltage appears across the self-inductance 58. As a result, at a given instant during this phase the current through the self-inductance 58 becomes lower than the output current, so that the switching over from the diode 112 to the transistor 102 takes place naturally under zero voltage conditions. When finally the current through the self-inductance 58 has become zero, the diode 90 will be naturally switched off under zero current conditions. The soft switching over from the diode 114 to the transistor 102 thus having been realized, the load current flows from the positive side of the power supply source 50 to the output 46 via the transistors 100 and 102.

Detailed Description Paragraph Right (32):
Considering the described switching example, to those skilled in the art it will be evident how other switching situation will be dealt with.

CLAIMS:

1. A power amplifier comprising:

a cascade of multilevel switching cells, wherein each multilevel switching cell includes

an input and an output,

two controllable switches, each switch with a respective diode which is connected antiparallel thereto, said diodes being connected in mutually opposed forward directions, wherein one end of each one of the two switches constitutes the input terminals of the switching cell, and the other ends of the two switches form the output terminals of the switching cell, and wherein said cascade of switching cells is formed in that the output terminals of a preceding switching cell are connected to the input terminals of a subsequent switching cell, and

a capacitor connected parallel to each controllable switch, the power amplifier further comprising

a capacitor connected between each pair of said interconnected input terminals and said interconnected output terminals,

a power supply source being connectable to said cascade of switching cells,

an inductive element, one end of which is connected to the output of the amplifier, and

at least a first and a second controllable resonant switch which are connected to the other end of the inductive element, wherein the first one of said resonant switches is connected to a point carrying a voltage which is higher than the output voltage of the amplifier whereas the second switch is connected to a point carrying a voltage which is lower than the output voltage of the amplifier.

2. A power amplifier as claimed in claim 1, further comprising a third controllable resonant switch which is connected to the other end of the inductive element and to a point carrying a voltage which is substantially equal to half the supply voltage.

3. A power amplifier as claimed in claim 1 further comprising a capacitor connected parallel to each of the resonant switches.

4. A power amplifier as claimed in claim 2, wherein the point carrying substantially half the supply voltage is realized by voltage division by means of two capacitors connected between points whereto a power supply source can be connected.

5. A power amplifier as claimed in claim 1 further comprising:

n supply points, the i.sup.th supply point supplying a voltage amounting to substantially i/n times the voltage of the power supply source, and

n controllable resonant switches which are connected to the other side of the inductive element, wherein the i.sup.th resonant switch is connected to the i.sup.th supply point.

6. A magnetic resonance imaging apparatus comprising

a gradient coil system for generating a magnetic gradient field in a measuring space of the apparatus, and

a power amplifier for supplying the gradient coil system with power signals in order to generate the magnetic gradient field, wherein the power amplifier is as claimed in claim 1.

7. The amplifier of claim 2 further comprising a capacitor connected parallel to each of the resonant switches.

DOCUMENT-IDENTIFIER: US 6111458 A
TITLE: Power amplifier and nuclear spin tomography apparatus employing same

Abstract Paragraph Left (1):
A power amplifier has an amplifier module and a pole changer module connected to the amplifier module, and during the operation of the power amplifier an amplifier current flows in a single current direction between the amplifier module and the pole changer module. The pole changer module optionally provides the amplifier current with unchanged current direction or with reversed current direction, as output current of the power amplifier. A nuclear spin tomography apparatus contains at least one such power amplifier. Such a power amplifier exhibits the required efficiency quantitatively and qualitatively, with low outlay and low cost.

Brief Summary Paragraph Right (2):
The present invention relates to a power amplifier and to a nuclear spin tomography apparatus employing same. The power amplifier can be used in all applications in which high output voltages and currents must be provided, in particular for inductive loads. For example, the amplifier is suited for driving motors and actuators in automation engineering, traffic engineering and plant engineering; however, an application of the amplifier in medical technology as a gradient amplifier in nuclear spin tomography (magnetic resonance imaging) is provided in particular.

Brief Summary Paragraph Right (4):
A nuclear spin tomography apparatus typically has an orthogonal gradient coil system that surrounds the patient chamber. For each gradient coil, a gradient amplifier is provided, via which the coil is supplied with a precisely regulated current. The precision and dynamic performance of the gradient current are decisive for the image quality. Thus, for example, currents up to 300 A must be maintained with a precision in the mA range, and for the production of sufficiently steep current edges, it must be possible for example to apply voltages up to over 1 kV to the gradient coil. In addition, the output current can have only a small residual ripple.

Brief Summary Paragraph Right (5):
German OS 40 24 160 discloses a gradient amplifier that has a switched output stage in a bridge circuit with four FET power transistors and four unbiased diodes respectively in parallel thereto. For each direction of the load current, two transistors diagonally opposite one another in the bridge circuit are clocked periodically, and in addition two transistors connected in series in the bridge circuit are driven with opposite phase.

Brief Summary Paragraph Right (6):
German OS 40 07 566, corresponding to U.S. Pat. No. 5,113,145, discloses a further gradient amplifier in which chokes are inserted between the bridge branches in order to avoid cross-currents. This gradient amplifier further has a specific construction for the reduction of parasitic inductances.

Brief Summary Paragraph Right (7):
Due to the exacting requirements described above, however, these known gradient amplifiers are very complex and expensive. High costs are caused in particular by the expensive components required for the amplifier, the complicated driving, the considerable structural size and the cooling requirements.

Brief Summary Paragraph Right (8):
An object of the present invention is to provide a power amplifier which avoids the

problems described above and while has the required efficiency qualitatively and quantitatively, with a low outlay and the lowest possible cost.

Brief Summary Paragraph Right (9):
The above object is achieved in accordance with the principles of the present invention in a power amplifier, such as a gradient amplifier of a nuclear spin tomography apparatus, having an amplifier module and a pole changer module connected to the amplifier module, wherein an amplifier current flows in a single current direction between the amplifier module and the pole changer module, and wherein the pole changer module can supply the amplifier current as an output current of the power amplifier with a polarity which is the same as the polarity of the current received from the amplifier module, or with a reversed polarity (reversed current direction).

Brief Summary Paragraph Right (10):
The invention is based on providing an additional pole changer module, in order to optionally provide an amplifier current originating from an amplifier module with the original current direction or with the reversed current direction as an output current. Surprisingly, the overall outlay for the gradient amplifier is thereby reduced, because the use of the pole changer module makes it possible to construct the amplifier module more simply for only one current direction. As stated above, due to the stringent requirements the outlay for the amplifier module is very high, so that the savings that can be achieved compensate the additional outlay for the pole changer module, which is of relatively simple construction.

Brief Summary Paragraph Right (11):
The amplifier module is preferably constructed as a switching amplifier. In this case, the advantages that can be realized by means of the invention are particularly significant. For example, in the gradient amplifiers known from German OS 40 24 160 and German OS 40 07 566, the switched output stage has two complete amplifier halves, each containing two active and two passive groups of components. For each current direction, only one of these two amplifier halves is active at a time. In accordance with the invention, in which the amplifier module need be constructed only for a single current direction, the outlay for this module, as well as for the allocated driver and auxiliary circuits, can be reduced by half. The amplifier module preferably has a bridge circuit containing only two groups of switching elements and two groups of unbiased diodes.

Brief Summary Paragraph Right (12):
In the gradient amplifiers known from German OS 40 24 160 and German OS 40 07 566, additional problems occur during switching procedures in the switching bridge. In order to avoid a bridge short-circuit, so-called dead times must be maintained between the respective edges of successive switching pulses. This limits the controllability of the amplifier, since the modulation amplitude is significantly less than 100%. According to German OS 40 07 566, additional components (chokes) are also provided in order to avoid cross-currents.

Brief Summary Paragraph Right (13):
Surprisingly, when used in a switching amplifier, the invention also solves these problems, since a reversal of the current direction of the amplifier module is no longer required. The amplifier module can be designed so that a bridge short-circuit is not possible, and, correspondingly, no dead times must be maintained and no additional components are required. This is particular effective when two pairs, each of one active component and one passive one, are provided in the amplifier module. These pairs are preferably connected in parallel, and an intermediate circuit voltage across them. MOSFET or IGBT transistors are preferably employed as active components (switching elements) of the amplifier module.

Brief Summary Paragraph Right (14):
The pole changer module is preferably constructed as a bridge circuit composed of four active control elements, forming two pairs, with the two control elements in each pair being connected in series. An amplifier voltage is preferably across each pair thus formed. A circuit of this sort enables the simple forwarding of the amplifier current in the unmodified or the reversed current direction, by switching two diagonally opposed control elements into a conductive state or into a non-conductive state. These operating states are designated as the switch-through mode and the reverse mode, respectively.

Brief Summary Paragraph Right (15):

The control elements of the pole changer module can each be an IGBT transistor or a MOSFET transistor as active components. In addition, an unbiased diode can be connected in parallel with the switching path of the transistor. In a MOSFET transistor, this unbiased diode can be formed by the internal diode of the transistor. An integrated control module can contain a control element or several control elements, with the allocated unbiased diodes if warranted. Since the control elements must cause switching only with the relatively low frequency of the output current, IGBT transistors are preferably used due to the low voltage necessary to make them conductive, and their high blocking ability.

Brief Summary Paragraph Right (16):
A control unit is preferably provided for driving the control and switching elements of the power amplifier. The control unit can be divided into several control modules. The division can be based on the discrete form of the control unit, or can be merely conceptual.

Brief Summary Paragraph Right (17):
In preferred embodiments, the switch-through and reversed operation of the pole changer module are mutually exclusively. For this purpose, the control elements are preferably driven with binary signals. The changeover between the two operating states preferably takes place as precisely at the zero crossing of the output current as possible. In the ideal case, neither disturbances nor power losses arise. In preferred embodiments, the zero crossing is either measured or is determined by the control unit in correspondence with the control signals of the amplifier module.

Brief Summary Paragraph Right (18):
In order to avoid possible difficulties associated with driving the amplifier module for very small amplifier current strengths and in the determination of the precise zero crossing time, in preferred embodiments the pole changer module is driven in linear fashion in a predetermined region of small output current strengths (e.g., from +1 A to -1 A). In this linear operation, just as in switch-through or reversed operation, only two control elements of the pole changer module are respectively driven. The driven element, however, are not switched through, but instead act as controllable resistances in order to regulate the output current without distortion, as in a linear output stage. Since the output current is relatively low, only small power losses occur.

Brief Summary Paragraph Right (19):
The savings achieved by the invention is particularly significant when, instead of a single amplifier module, the power amplifier is formed by several amplifier modules connected in series, to which a single pole

Brief Summary Paragraph Right (20):
changer module is connected. The amplifier modules are preferably driven with chronologically offset pulse-width-modulation signals, in order to achieve an output voltage with very low residual ripple. In a further embodiment, several power amplifiers, each with a separate pole changer module, as well as other constructive units (e.g., boosters), can be connected in series, and can be connected to a gradient coil that serves as a load.

Drawing Description Paragraph Right (1):
FIG. 1 is a block diagram of a power amplifier constructed in accordance with the principles of the present invention, in the form of a gradient amplifier for a nuclear magnetic resonance tomography apparatus.

Drawing Description Paragraph Right (2):
FIG. 2 shows two current curves and two control curves for explaining a first manner of operating the power amplifier shown in FIG. 1.

Drawing Description Paragraph Right (3):
FIG. 3 shows two current curves and two control curves for explaining a second manner of operating the power amplifier shown in FIG. 1.

Detailed Description Paragraph Right (1):
The gradient amplifier, shown in FIG. 1, of a nuclear spin tomography apparatus includes an amplifier module 10 that is connected to a pole changer module 16 via connection lines 12, 14. An amplifier voltage U.sub.v is across the pole changer module 16, and an amplifier current I.sub.v flows between the amplifier module 10

and the pole changer module 16.

Detailed Description Paragraph Right (2):
The amplifier module 10 contains, a voltage source 18 and a switched output stage 20 connected thereto. The voltage source 18 provides a constant intermediate circuit voltage U.sub.z for the switched output stage 20, whereby an intermediate circuit current I.sub.z flows in the intermediate circuit formed by the voltage source 18 and the switched output stage 20.

Detailed Description Paragraph Right (3):
The switched output stage 20 contains a bridge circuit composed of two switching elements 22, 24 and two unbiased diodes 26, 28. The switching elements 22, 24 are constructed as MOSFET power transistors. The switching element 22 is connected to the positive pole of the voltage source 18 and to the cathode of the unbiased diode 26 and the connection line 12. The anode of the unbiased diode 26 and a terminal of the switching element 24 are connected to the negative pole of the voltage source 18, and the other terminal of the switching element 24 is connected to the anode of the unbiased diode 28 and to the connection line 24. The cathode of the unbiased diode 28 is connected to the positive pole of the voltage source 18. The pole changer module 16 is connected into the bridge cross-branch of the switched output stage 20 via the connection lines 12, 14.

Detailed Description Paragraph Right (4):
The pole changer module 16 has four control elements 30-36, arranged in a bridge circuit. Each control element 30-36 is constructed as an IGBT module, with an IGBT (insulated gate bipolar transistor) 38-44, and an unbiased diode 46-52 connected in parallel thereto. The two control elements 30, 32, or 34, 36, in each pair are connected in series, and are connected to the connection lines 12, 14. An output terminal 54 is connected to the control elements 30, 32, and an additional output terminal 56 is connected to the control elements 34, 36 via a current sensor 58.

Detailed Description Paragraph Right (5):
A gradient coil 60 that acts as a load is connected to the gradient amplifier via the output terminals 54, 56. The gradient coils 60 and the current sensor 58 are thus arranged in the bridge cross-branch of the bridge circuit formed from the four control elements 30-36. An output current I.sub.A flows through the gradient coil 60, as a result of an output voltage U.sub.A across the terminals 54, 56.

Detailed Description Paragraph Right (6):
A control unit is fashioned from two control modules 64, 66, connected with one another via a trunk group 62. The control unit serves for precisely controlling the output current I.sub.A, according to a predetermined current curve shape or a target current value. For this purpose, the first control module 64 is connected with the gate terminals of the two switching elements 22, 24, in order to drive these with pulse-width modulation signals. The second control module 66 drives of the gates of the control elements 30-36 with control signals S.sub.1 -S.sub.4. The second control module 66 receives and processes an output current measurement value signal from the current sensor 58, and supplies this signal to the first control module 64 via a line of the trunk group 62, as an actual current value. In addition, the second control module 66 receives a mode signal from the first control module 64 via a further line of the trunk group 62, this signal indicating the operating state to be set for the control elements 30-36.

Detailed Description Paragraph Right (7):
In FIG. 2, a target curve of the output current I.sub.A flowing through the gradient coil 60 is shown as an example. The output current I.sub.A is negative at the outset, and first decreases (with regard to magnitude) to zero (time t.sub.1), and then increases to a positive maximum value (e.g., 300 A). After e.g. 20 .mu.s the output current I.sub.A falls rapidly to zero (time t.sub.2). After this positive half wave of the output current I.sub.A in the time period t.sub.1 -t.sub.2, there follows a negative half wave (time period t.sub.2 -t.sub.3). This current cycle is repeated continuously.

Detailed Description Paragraph Right (8):
During the operation of the gradient amplifier of FIG. 1, the amplifier current I.sub.v flows between the amplifier module 10 and the pole changer module 16, according to the current curve shown in FIG. 2. The amplifier current I.sub.v is always positive, and thus flows only in a single direction. As can be seen from FIG. 2, the amplifier current I.sub.v always agrees in its magnitude with the output

current I.sub.A. In the time segment t.sub.1 -t.sub.2, and after the time t.sub.3, the amplifier current and the output current have the same sign, while before time t.sub.1 and during the time segment t.sub.2 -t.sub.3 the current direction of the output current I.sub.A is reversed in relation to that of the amplifier current I.sub.v.

Detailed Description Paragraph Right (9):
In order to reverse the polarity of the output current I.sub.A in a suitable manner, the control elements 30-36 of the pole changer module 16 are correspondingly driven by the second control module 66. The control signal S.sub.1 applied to the control element 30 for this purpose, and the control signal S.sub.2 applied to the control element 32, are shown in FIG. 2. A high signal level causes a conductive state of the allocated control element, and a low signal level causes a blocking state. The control signal S.sub.3 (control element 34) agrees with the control signal S.sub.2, and the control signal S.sub.4 (control element 36) agrees with the control signal S.sub.1.

Detailed Description Paragraph Right (10):
As can be seen from FIG. 2, the pole changer module 16 operates in the switch-through mode in the time period t.sub.1 -t.sub.2 and after time t.sub.3. The control elements 30 and 36 (control signals S.sub.1 and S.sub.4) conduct, and the control elements 32 and 34 (control signals S.sub.2 and S.sub.3) block. In contrast, before time t.sub.1 and in the time period t.sub.2 -t.sub.3 the pole changer module 16 operates in the reverse mode. Here, the switching states of the control elements 30-36 are inverted in relation to the switch-through operation.

Detailed Description Paragraph Right (11):
The operating state or mode to be set is indicated to the second control module 66 by the mode signal produced by the first control module 64. The changeover times t.sub.1, t.sub.2, t.sub.3, . . . between the two operating states are thereby determined by the zero crossings of the output current I.sub.A In order to determine the zero crossings, the output current measurement value signal of the current sensor 58 is evaluated by the second control module 66.

Detailed Description Paragraph Right (12):
The amplifier module 10 driven by the first control module 64 produces the amplifier voltage U.sub.v in a known way by pulse-width modulation of the intermediate circuit voltage U.sub.z, in order to produce the amplifier current I.sub.v shown in FIG. 2. Thus, for example during the constant current maximum in the middle segment of the time period t.sub.1 -t.sub.2, only a relatively low amplifier voltage U.sub.v (which is essentially equal to the output voltage U.sub.A) is required to compensate ohmic losses in the gradient coil 60. For this purpose, the switching elements 22, 24 are driven with a relatively low pulse duty factor (e.g., 10%).

Detailed Description Paragraph Right (13):
During the steep current increase at the beginning of the time period t.sub.1 -t.sub.2, the switching elements 22, 24 are essentially constantly switched through, so that the complete intermediate circuit voltage U.sub.z is across to the gradient coil 60 as the output voltage U.sub.A, via the switching elements 22, 24 and the control elements 30, 36. In contrast, during the rapid current decrease at the end of the time period t.sub.1 -t.sub.2 the switching elements are for the most part in a blocking state. The magnetic energy stored in the gradient coil 60 is then fed back into the voltage source 18 via the unbiased diodes 26, 28, whereby the intermediate circuit voltage U.sub.z counteracts the current flow in the gradient coil 60. During the current decrease, the amplifier voltage U.sub.v is negative, but the amplifier current I.sub.v remains positive.

Detailed Description Paragraph Right (14):
Drive of the amplifier module 10 during the time period t.sub.2 -t.sub.3 takes place correspondingly, whereby the reverse mode of the pole changer module 16, which was activated by the mode signal originating from the first control module 64, is taken into account correspondingly in driving the switching elements 22, 24.

Detailed Description Paragraph Right (15):
The alternative construction shown in FIG. 3 is likewise based on the circuit of FIG. 1, but the driving of the circuit elements 22, 24 and of the control elements 30-36 differs from that described previously. The only visible difference from FIG. 2 is that the control signals S.sub.1 and S.sub.2 are not binary signals, but rather analog signals, with which the control elements 30-36 can be operated by variation

of the gate-emitter voltage, as controllable resistances. Again, the control signal S.sub.3 is equal to the control signal S.sub.2, and the control signal S.sub.4 is equal to the control signal S.sub.1.

Detailed Description Paragraph Right (16):
In FIG. 3, the zero crossings of the output current I.sub.A take place at times t.sub.2, t.sub.5 and t.sub.8. During times t.sub.1 -t.sub.3, t.sub.4 -t.sub.6 and t.sub.7 -t.sub.8, the magnitude of the output current I.sub.A lies under a predetermined boundary value, here for example .+-.1 A. During these time periods, the pole changer module 16 operates in linear operation. That is, though the amplifier current I.sub.v does continue to flow through the gradient coil 60 as the output current I.sub.A of the amplifier, with unchanged current direction (time periods t.sub.2 -t.sub.3, t.sub.4 -t.sub.5 and t.sub.8 -t.sub.9) or with reversed current direction (time periods t.sub.1 -t.sub.2, t.sub.5 -t.sub.6 and t.sub.7 -t.sub.8), according to the level of the mode signal, this amplifier current I.sub.v is nonetheless controlled in linear fashion by the respective two active control elements 30, 36, or 32, 34, respectively.

Detailed Description Paragraph Right (17):
For example, in the time period to t.sub.1 -t.sub.2 the control elements 32, 34 are gradually brought from a conductive state into a blocking state (signal S.sub.2), so that the output current I.sub.A approximates zero in a linear and distortion-free fashion. In contrast, in the time period t.sub.2 -t.sub.3 the resistance of the control elements 30, 36 is gradually reduced (signal S.sub.1), in order to allow the output current I.sub.A to increase gradually. This manner of driving the control elements 30-36, which takes place via the second control module 66, avoids non-linearities and disturbances, which could otherwise occur in the region around the zero crossing, given a pure pulse-width modulation of the switched output stage 20 with an extremely low pulse-duty ratio.

Detailed Description Paragraph Right (18):
In further variant embodiments, uniform control is provided, for example, by a control computer executing a control program. The two control modules are then regarded only as a conceptual division of the functions of the control unit. In addition, the zero crossing of the output current I.sub.A need not necessarily be measured; rather, it can be determined corresponding to the drive of the switching elements 22, 24.

CLAIMS:

1. A power amplifier comprising:

an amplifier module, said amplifier module comprising a voltage source electrically connected to a switched output stage, and said switched output stage comprising a bridge circuit having a first bridge arm containing a first switching element and a first recovery diode and a second bridge arm containing a second switching element and a second recovery diode;

a pole changer module electrically connected to said amplifier module, said amplifier module producing an amplifier current flowing in a single current direction between said amplifier module and said pole changer module; and

said pole changer module comprising means for producing an amplifier output current optionally having an amplifier output current direction which is the same as said single current direction or which is reversed with respect to said single current direction.

2. A power amplifier as claimed in claim 1 wherein said amplifier module comprises a voltage source electrically connected to a switched output stage.

3. A power amplifier as claimed in claim 2 wherein said switched output stage comprises a bridge circuit having a first bridge arm containing a first switching element and a first recovery diode and a second bridge arm containing a second switching element and a second recovery diode.

4. A power amplifier as claimed in claim 1 wherein said first switching element and said first recovery diode are connected in series, at a first node, in said first bridge arm and wherein said second switching element and said second recovery diode are connected in series, at a second node, in said second bridge arm, wherein said

voltage source is connected across each of said first and second bridge arms for producing an intermediate circuit voltage across said first and second bridge arms, and wherein said pole changer module is connected across said first node and said second node.

5. A power amplifier as claimed in claim 1 wherein said pole changer module comprises a bridge circuit containing four control elements.

6. A power amplifier comprising:

an amplifier module;

a pole changer module electrically connected to said amplifier module, said amplifier module producing an amplifier current flowing in a single current direction between said amplifier module and said pole changer module; and

said pole changer module comprising means for producing an amplifier output current optionally having an amplifier output current direction which is the same as said single current direction or which is reversed with respect to said single current direction, said pole changer module comprising a bridge circuit containing four control elements, and said control elements comprising a first pair of control elements connected in series at a first node and a second pair of control elements connected in series at a second node, wherein each of said first pair of control elements and said second pair of control elements is connected across an amplifier voltage produced by said amplifier module, and said pole changer module having two output terminals respectively connected to said first node and said second node.

7. A power amplifier as claimed in claim 1 wherein said amplifier module comprises a voltage source connected to a switched output stage, said switched output stage comprising a bridge circuit containing two switching elements and two unbiased diodes, and said power amplifier further comprising a control module for driving said switching elements for

producing said amplifier current in said single current direction by pulse-width modulation.

8. A power amplifier as claimed in claim 7 wherein said control module is a first control module, and wherein said pole changer module comprises a bridge circuit containing four control elements, and said power amplifier further comprising a second control module for driving said control elements of said pole changer module to place the control elements in respective states for providing said output current with the same current direction as said single direction of said amplifier current or with a current direction which is reversed compared to said single current direction.

9. A power amplifier as claimed in claim 8 wherein said output current exhibits a zero crossing, and wherein said second control module comprises means for driving said control elements either in a forward-conducting state or in a reverse-conducting state, with switching between said forward conducting state and said reverse conducting state occurring approximately at said zero crossing of said output current.

10. A power amplifier as claimed in claim 8 wherein said control elements respectively comprise controllable resistances, and wherein said second control module comprises means for linearly operating said control elements to control the respective controllable resistances thereof.

11. A power amplifier as claimed in claim 10 further comprising means for informing said second control module when said output current has a current amplitude between a predetermined positive threshold value and a predetermined negative threshold value, and wherein said second control module comprises means for linearly operating said control elements of said pole changer module when said output current is between said predetermined positive threshold value and said predetermined negative threshold value.

12. A power amplifier as claimed in claim 1 wherein said amplifier module is a first amplifier module, and further comprising a plurality of additional amplifier modules, identical to said first amplifier module, said first amplifier module and said plurality of additional amplifier modules being connected in series and

including a last series-connected amplifier module, said last series-connected amplifier module being electrically connected to said pole changer module.

13. A power amplifier as claimed in claim 3 wherein said first switching element and said first recovery diode are connected in series, at a first node, in said first bridge arm and wherein said second switching element and said second recovery diode are connected in series, at a second node, in said second bridge arm, wherein said voltage source is connected across each of said first and second bridge arms for producing an intermediate circuit voltage across said first and second bridge arms, and wherein said pole changer module is connected across said first node and said second node.

14. A power amplifier as claimed in claim 6 wherein said amplifier module comprises a voltage source connected to a switched output stage, said switched output stage comprising a bridge circuit containing two switching elements and two unbiased diodes, and said power amplifier further comprising a control module for driving said switching elements for producing said amplifier current in said single current direction by pulse-width modulation.

15. A power amplifier as claimed in claim 14 wherein said control module is a first control module, and said power amplifier further comprising a second control module for driving said control elements of said pole changer module to place the control elements in respective states for providing said output current with the same current direction as said single direction of said amplifier current or with a current direction which is reversed compared to said single current direction.

16. A power amplifier as claimed in claim 15 wherein said output current exhibits a zero crossing, and wherein said second control module comprises means for driving said control elements either in a forward-conducting state or in a reverse-conducting state, with switching between said forward conducting state and said reverse conducting state occurring approximately at said zero crossing of said output current.

17. A power amplifier as claimed in claim 15 wherein said control elements respectively comprise controllable resistances, and wherein said second control module comprises means for linearly operating said control elements to control the respective controllable resistances thereof.

18. A power amplifier as claimed in claim 17 further comprising means for informing said second control module when said output current has a current amplitude between a predetermined positive threshold value and a predetermined negative threshold value, and wherein said second control module comprises means for linearly operating said control elements of said pole changer module when said output current is between said predetermined positive threshold value and said predetermined negative threshold value.

19. A power amplifier as claimed in claim 6 wherein said amplifier module is a first amplifier module, and further comprising a plurality of additional amplifier modules, identical to said first amplifier module, said first amplifier module and said plurality of additional amplifier modules being connected in series and including a last series-connected amplifier module, said last series-connected amplifier module being electrically connected to said pole changer module.

DOCUMENT-IDENTIFIER: US 6031422 A
TITLE: Power amplifier and nuclear magnetic resonance tomography apparatus employing same

Abstract Paragraph Left (1):
A power amplifier has a supply assembly for offering an intermediate circuit voltage and an output stage connected to the supply assembly for generating an output voltage from the intermediate circuit voltage. The supply assembly contains at least two voltage sources that can be optionally connected in parallel or in series via at least one switch stage. A nuclear magnetic resonance tomography apparatus can be equipped with such a power amplifier. The power amplifier exhibits the required high performance capability in quantitative and qualitative terms, with low losses.

Brief Summary Paragraph Right (2):
The invention is directed to a power amplifier and to a nuclear magnetic resonance tomography apparatus employing same. The power amplifier can be utilized in all fields wherein high output voltages and currents must be offered, particularly for inductive loads. For example, the amplifier is suitable for driving motors and actuators in automation technology, traffic technology and systems technology. In particular, however, the amplifier is suitable for use in medical technology as a gradient amplifier in nuclear magnetic resonance tomography (magnetic resonance imaging).

Brief Summary Paragraph Right (4):
A nuclear magnetic resonance tomography apparatus typically has an orthogonal gradient coil system that surrounds the patient volume. A gradient amplifier which supplies the coil with an exactly regulated current is provided for each gradient coil. For example, the current through each gradient coil can reach values up to 300 A in a predetermined current curve that must be adhered to with a precision in the mA range. In order to achieve the steep current edges that are also required, voltages of, for example, over 1000 V must, for example, be applied to the gradient coil. The precision and dynamics of the gradient current are critical for the image quality. Moreover, the gradient amplifier must offer adequate power in order to accommodate the ohmic losses given a constant current flow of, for example, 300 A through the gradient coil, even in the case of longer current pulses.

Brief Summary Paragraph Right (5):
U.S. Pat. No. 5,515,002 discloses a gradient amplifier having a supply assembly for offering a intermediate circuit voltage and an output stage connected to the supply assembly for generating an output voltage from the intermediate circuit voltage. The output stage is fashioned as a switched output stage employing bridge circuitry, with MOSFET transistors being utilized as switch elements.

Brief Summary Paragraph Right (6):
The intermediate circuit voltage in this known gradient amplifier must be correspondingly high because of the high output voltages to be achieved for fast current variations. Further, a high switching frequency is required in order to achieve the required current regulating precision given slight residual ripple. For these reasons, high switching losses occur at the MOSFET transistors of the output stage.

Brief Summary Paragraph Right (7):
An object of the present invention, is to provide a power amplifier which avoids the aforementioned problems and which exhibits the required performance capability in quantitative and qualitative terms, with low losses.

Brief Summary Paragraph Right (8):
The above object is achieved in accordance with the principles of the present invention in a power amplifier, particularly a gradient amplifier for use in a nuclear magnetic resonance tomography apparatus, having a supply assembly which produces an intermediate circuit voltage, an output stage connected to the supply assembly which generates an output voltage from the intermediate circuit voltage, and wherein the supply assembly contains at least two voltage sources which can be selectively connected in parallel or in series via at least one switch stage.

Brief Summary Paragraph Right (9):
Because at least two voltage sources of the supply assembly are optionally switchable parallel or in series, the intermediate circuit voltage can be matched to the output voltage of the amplifier which is to be achieved. Given high current rise rates, there is the possibility of temporarily offering a correspondingly high intermediate circuit voltage by a series connection of the voltage sources. When, by contrast, a lower output voltage is required (possibly given a high current intensity), the voltage sources can be connected in parallel. A higher on/off ratio (duty cycle) of the switch elements of the output stage is possible as a result of the lower intermediate circuit voltage achieved in this way, so that significantly lower switching losses occur. Moreover, the required power is uniformly divided among the voltage sources, so that high continuous powers are possible. Overall, the inventive gradient amplifier thus exhibits considerable advantages with respect to dissipated power, cooling requirements, structural size and costs.

Brief Summary Paragraph Right (10):
In a preferred embodiment, the supply assembly of the power amplifier is formed of a number of branches connected in parallel. In each branch one of the voltage sources is connected in series with at least one diode. Each switch is preferably connected to opposite poles of two voltage sources. The voltage sources are preferably connected in series when the switch is conductive (in the momentary direction of the current) but are otherwise connected in parallel.

Brief Summary Paragraph Right (11):
The supply assembly preferably includes two, three or more voltage sources that are driven in common in a preferred embodiment and are thus always either all connected in series or all connected in parallel. in alternative embodiments series and parallel circuitry can be used in combination so as to offer intermediate values of the intermediate circuit voltage. Given, for example, four voltage sources, two of these can be connected in parallel and these pairs can in turn be connected in series.

Brief Summary Paragraph Right (12):
In the feedback mode of the power amplifier, the magnetic energy stored in the inductive load can be returned to the power amplifier via unbiased diodes. The voltage sources are preferably connected in series for faster current dismantling. This can ensue by including one diode in each switch arrangement. Alternatively or additionally, each switch arrangement can be actively driven in a feedback mode in order to connect the voltage sources in series. The combination of these two possibilities has the advantage that transition problems are avoided given a reversal of the current direction due to an activation of the switch arrangement at the zero-axis crossing. In preferred embodiments, the recognition of the onset of the feedback mode ensues with an evaluation of the current curve or by direct measurement at the switch devices.

Brief Summary Paragraph Right (13):
In the normal mode of the power amplifier, the voltage sources are preferably connected in series when the output voltage to be achieved exceeds a predetermined threshold, and thus a high intermediate circuit voltage is required. Other switching strategies are also possible, particularly those wherein a future current requirement or a charge condition of the individual voltage sources is taken into consideration.

Brief Summary Paragraph Right (14):
The output stage preferably includes a switch bridge and generates the output voltage with pulse-width modulation.

Drawing Description Paragraph Right (1):
FIG. 1 is a block circuit diagram of a supply assembly in the inventive power

amplifier.

Drawing Description Paragraph Right (2):
FIG. 2 is a block circuit diagram of a known output stage which can be used in the inventive power amplifier.

Drawing Description Paragraph Right (3):
FIG. 3 illustrates a current curve and voltage curve in the inventive power amplifier.

Drawing Description Paragraph Right (4):
FIG. 4 IS a block circuit diagram of a modified embodiment of the supply assembly of FIG. 1.

Detailed Description Paragraph Right (1):
The supply assembly 10 shown in FIG. 1 includes a first voltage source 12 for offering a first supply voltage U.sub.1, a second voltage source 14 for offering a second supply voltage U.sub.2, a first diode 16, a second diode 18 and a switch stage 20. In the exemplary embodiment described here, the voltages U.sub.1 and U.sub.2 are equal.

Detailed Description Paragraph Right (2):
A first branch of the supply assembly 10 is formed by the first voltage source 12 and the first diode 16, whose anode is connected to the positive pole of the first voltage source 12. Together, the second voltage source 14 and the second diode 18, which has its cathode connected to the negative pole of the second voltage source 14, form a second branch of the supply assembly 10. The two branches are connected in parallel and are connected to two intermediate circuit terminals 26. An intermediate circuit voltage U.sub.z generated by the supply assembly 10 is across terminals 26.

Detailed Description Paragraph Right (3):
The switch stage 20 is formed of a MOSFET transistor 22 with an inherent diode 24 and is connected between the two branches, to the positive pole of the first voltage source 12 and the negative pole of the second voltage source 14. MOSFET modules suitable for the switch stage 20 are available, for example, under the model designation "Siemens BSM". The cathode of the inherent diode 24 is connected to the positive pole of the first voltage source 12 and the anode is connected to the negative pole of the second voltage source 14. A control terminal (gate terminal) of the switch stage 20 is connected to a control unit 28.

Detailed Description Paragraph Right (4):
FIG. 2 shows a known output stage 30 that is connected to the supply assembly 20 via the intermediate circuit terminals 26. The output stage 30 is fashioned on the basis of bridge circuitry with four bridge arms. The bridge arms respectively contain a switch element 32-38 and diodes 40-46, with each switch element 32-38 connected in series with the respective diode 40-46 in the same bridge arm. The switch elements 32-38 are MOSFET transistors that each contain an inherent diode. The four bridge arms are arranged in parallel and are connected to the intermediate circuit voltage U.sub.Z. The switch elements 32-38 are driven by the control unit 28, that includes a current regulator and pulse-width modulator.

Detailed Description Paragraph Right (5):
Respective inductors 48-54 are connected to the junctions of the series-connected switch elements 32-38 and diodes 40-46. The inductors 48-54 are arranged in two pairs, with the inductors in each pair connected in series. The junction between each inductor pair is connected to one of the output terminals 56. A predominantly inductive load 58, a gradient coil here, is connected to the two output terminals 56. An output voltage U.sub.A of the output stage 30 is across the load 58, and an output current I.sub.A flows through the load 58. The functioning of the output stage 30 and its structure are disclosed in greater detail in German OS 40 07 566 (corresponding to U.S. Pat. No. 5,113,145), the latter of which is incorporated herein by reference.

Detailed Description Paragraph Right (6):
All components of the gradient amplifier are wired by low-inductance circuit boards with planar conductor structures in order to avoid parasitic voltage spikes, as described in German OS 40 07 566 and U.S. Pat. No. 5,113,145.

Detailed Description Paragraph Right (7):
During operation of the gradient amplifier shown in FIG. 1 and FIG. 2, the control unit 28 drives the switch stage 20 of the supply assembly 10 and the switch elements 32-38 of the output stage 30. When the switch stage 20 (either the MOSFET transistor 22 or the inherent diode 24) is conducting, the voltage sources 12 and 14 are connected in series. When, by contrast, the switch stage 20 is open (non-conducting), then the voltage sources 12 and 14 deliver the intermediate circuit voltage U.sub.Z in parallel circuitry.

Detailed Description Paragraph Right (8):
The control unit 28 determines the required output voltage U.sub.A as well as the operating condition (normal or feedback mode) of the power amplifier and switches the MOSFET transistor 22 into a conductive state when either the output voltage U.sub.A exceeds a predetermined threshold or a feedback mode occurs. Further, the control unit 28 drives the switch elements 32-38 of the output stage 30 in order to generate the output current I.sub.A corresponding exactly to a reference current value by pulse-width modulation.

Detailed Description Paragraph Right (9):
Exemplary curves of the output current I.sub.A and of the output voltage U.sub.A are shown in FIG. 3. In a time span t.sub.1 -t.sub.2 that, for example, can amount to 1 ms, the output current I.sub.A in FIG. 3 rises from zero to a maximum value, for example +300 A. The output current remains constant in the time span t.sub.2 -t.sub.3 and then drops back to zero in the time span t.sub.3 -t.sub.4. Further, a negative output current I.sub.A flows through the load 58 in the time span t.sub.5 -t.sub.6, assuming a maximum value of, for example, -300 A at time t.sub.6.

Detailed Description Paragraph Right (11):
The high current rise rate in the time span t.sub.1 -t.sub.2 that requires a high output voltage U.sub.A exceeds the threshold prescribed in the control unit 28, so that the MOSFET transistor 22 is placed in its conducting state, and the voltage sources 12 and 14 are thus connected in series. The voltage U.sub.1 +U.sub.2 (or 2.multidot.U.sub.1 because U.sub.1 is equal to U.sub.2) is now across the terminals 26 as the intermediate circuit voltage U.sub.Z. The output voltage U.sub.A can be regulated up to the full intermediate circuit voltage U.sub.Z.

Detailed Description Paragraph Right (12):
If, deviating from FIG. 3, only a gradual rise of the output voltage U.sub.A is required, the control unit 28 likewise doubles the intermediate circuit voltage U.sub.Z as soon as the threshold is exceeded. The voltage discontinuity of the intermediate circuit voltage U.sub.Z is immediately compensated by a corresponding drive of the switch elements 32-38 of the output stage 30 (reducing the active pulse widths), so that a linear regulation, without any discontinuities of the output voltage U.sub.A and of the output current I.sub.A is assured.

Detailed Description Paragraph Right (13):
When the current rise rate falls below the threshold in terms of magnitude, or when (in the time span t.sub.2 -t.sub.3 in FIG. 3) the current reaches the pulse maximum, then the control unit 28 places the MOSFET transistor 22 in a blocking state. Via the diodes 16 and 18 acting as decoupling diodes, the voltage sources 12 and 14 are thus switched into the parallel mode. The intermediate circuit voltage drops to U.sub.Z =U.sub.1 =U.sub.2, resulting in significantly lower switching losses at the switch elements of the output stage 30, and the power required for the compensation of the ohmic losses in the load 58 is uniformly distributed between the voltage sources 12 and 14.

Detailed Description Paragraph Right (14):
The inductive load 58 is rapidly demagnetized (negative current ramp di/dt) in the time span t.sub.3 -t.sub.4. The magnetic energy (1/2.multidot.L.multidot.I.sub.A.sup.2) stored in the load 58 is thereby fed back into the voltage sources 12 and 14. A high intermediate circuit voltage U.sub.Z is again required for rapidly dismantling the output current I.sub.A in this feedback mode. Even without the intervention of the control unit 28, the voltage sources 12 and 14 are connected in series here because the diodes 16 and 18 are blocking in the feedback path and the inherent diode 24 of the switch means 20 is conductive. Regardless of the amplitude of the intermediate circuit voltage U.sub.Z, a continuous current regulation by pulse-width modulation of the output stage 30 also ensues.

Detailed Description Paragraph Right (16):
A negative output current I.sub.A is built up in the load 58 beginning at the point in time t.sub.5. Since the polarity of the output current I.sub.A is defined in a known way by the drive of the switch bridge in the output stage 30 (and the intermediate circuit voltage U.sub.Z always exhibits a constant polarity), the switch unit 20 is driven here in the same way that was set forth above for a positive output current I.sub.A.

Detailed Description Paragraph Right (17):
As presented above, the inherent diode 24 is in a conducting stage in the feedback mode, so that an additional drive of the MOSFET transistor 22 is actually not required. If, however, a direct change from one direction of the output current I.sub.A to the other direction is to ensue, the MOSFET transistor 22 must be switched to the conducting state no later than the zero-axis crossing. If cut-in took place exactly at the zero-axis crossing, however, this would be time-critical and could lead to undesired noise pulses. The control unit 28 therefore always places the MOSFET transistor 22 into a conductive state when a voltage in the conducting direction is across the inherent diode 24. This avoids the problem just described and is possible without further difficulty since the drain-source channel of the MOSFET transistor 22 is conductive in both directions.

Detailed Description Paragraph Right (18):
An alternative embodiment of the supply assembly 10 shown in FIG. 4 is expanded by a third branch compared to that shown in FIG. 1. This third branch includes a third voltage source 14' for offering a third supply voltage U.sub.3, with U.sub.1 =U.sub.2 =U.sub.3. The third voltage source 14' is connected to the intermediate circuit terminals 26 via a further diode 18'. An additional diode 16' is connected as a decoupling diode between the positive pole of the second voltage source 14 and the corresponding intermediate circuit terminal 26.

Detailed Description Paragraph Right (19):
Like the switch stage 20, a further switch stage 20' is composed of a MOSFET transistor 22' with an inherent diode 24' and is connected between the second and the third branches of the supply assembly 10, to the positive pole of the second voltage source 14 and to the negative pole of the third voltage source 14'. A control input of the switch stage 20' is connected to the control means 28.

Detailed Description Paragraph Right (20):
During operation of a gradient amplifier that contains the supply assembly 10 of FIG. 4 and the output stage 30 of FIG. 2, the two switch stages 20 and 20' in the exemplary embodiment described here are always driven in common. When the switch stages 20 and 20' are conducting, then the voltage sources 12, 14 and 14' are connected in series. The intermediate circuit voltage U.sub.Z thus amounts to U.sub.1 +U.sub.2 +U.sub.3 or, since the voltages U.sub.1 through U.sub.3 are the same, three times the value of any of these voltages. When the switch stages 20 and 20' are open (non-conducting), then the voltage sources 12, 14 and 14' act in parallel and U.sub.Z =U.sub.1 =U.sub.2 =U.sub.3 applies. A variation of the intermediate circuit voltage by a factor of 3 is thus possible overall given the circuit of FIG. 4.

Detailed Description Paragraph Right (21):
In the alternative embodiments of the supply assemblies shown in FIG. 1 and FIG. 4, the switch stages 20 and 20' can be formed by other suitable switch elements, for example IGBTs (insulated gate bipolar transistors). Separate unbiased diodes, which are already inherently present in MOS field effect transistors, may possibly then be connected with opposite polarity for the feedback. Further, more than three voltage sources can be provided or the voltage sources can exhibit different voltages. Switching to produce combinations of series and parallel circuitry, rather than only series or only parallel, are also possible.

Detailed Description Paragraph Left (1):
is required in order to produce the output current I.sub.A in the load 58, whereby L indicates the inductance of the inductive load 58, R the ohmic resistance thereof and di/dt the current rise rate (steepness). Given the example shown in FIG. 3, a high output voltage U.sub.A in terms of magnitude is required during the steep current ramps in the time spans t.sub.1 -t.sub.2, t.sub.3 -t.sub.4 and t.sub.5 -t.sub.6, whereas only a relatively slight output voltage U.sub.A for compensating the ohmic losses in the load 58 is required for holding the maximum value in the time span t.sub.2 -t.sub.3.

CLAIMS:

1. A power amplifier comprising:

a supply assembly which produces an intermediate circuit voltage at a supply assembly output;

an output stage, comprising a plurality of driveable switch elements, connected to said supply assembly output for generating an output voltage at an output stage output from said intermediate circuit voltage;

said supply assembly comprising at least two voltage sources and at least one switch stage, and means for optionally connecting said at least two voltage sources in parallel or in series via said at least one switched stage; and

control means for driving said switch elements of said output stage and for operating said at least one switch stage for connecting said at least two voltage sources in series when a desired output voltage exceeds a predetermined threshold.

2. A power amplifier as claimed in claim 1 wherein said supply assembly comprises a plurality of branches connected in parallel, each of said branches containing one of said voltage sources and at least one diode connected in series with the voltage source in the branch.

3. A power amplifier as claimed in claim 1 wherein each of said two voltage sources has two poles of opposite polarity, and wherein said switch stage is connected between said at least two voltage sources to respective poles of the voltage sources of opposite polarity.

4. A power amplifier as claimed in claim 1 wherein said at least one switch stage comprises at least one diode for switching said at least two voltage sources in series in a feedback mode.

5. A power amplifier as claimed in claim 1 wherein said control means comprises means for connecting said voltage sources in series in a feedback mode.

6. A power amplifier as claimed in claim 1 wherein said output stage contains a switch bridge, and wherein said output stage comprises means for generating said output voltage from said intermediate circuit voltage using said switch bridge by pulse-width modulation.